South West Partnership for Environment and Economic Prosperity

SWEEP-OWWL:

Operational Wave and Water Level model

A technical note provided by: Coastal Processes Research Group,

University of Plymouth, Devon, UK.

Date: 22/01/19

Project code: SWEEP-OWWL

Document code/version: SOTN_V1

UNIVERSITY OF PLYMOUTH

SWEEP OWWL Operational Wave & Water Level Model

All queries related to this document should be directed to the University of Plymouth SWEEP Team: School of Biological and Marine Sciences, Reynolds Building, Plymouth University, Drake Circus, Plymouth, Devon PL4 8AA

Email: cmar@plymouth.ac.uk
Telephone: +44 1752 586177
Web: www.plymouth.ac.uk/cmar
Twitter: @pu_cmar

UNIVERSITY OF PLYMOUTH

sweep
Applying research to benefit our environment and economy

Document Information

Document permissions	SWEEP
Project name	SWEEP-OWWL
Report date	January 2019
Report number	SOTN_V1
Project lead	Dr Christopher Stokes
Project manager	Prof. Gerd Masselink

Document history

Date	Issue	Prepared	Approved	Authorised	notes
22/01/18	Revised	CS	TP	GM	
15/01/18	Draft	CS	TP	GM	

Document authorisation

Prepared	Approved	Authorised
Dr Christopher Stokes	Dr Tim Poate	Prof. Gerd Masselink

SWEEP-OWWL: Operational Wave and Water Level model

Executive Summary

Predicting wave runup elevation and overtopping volume is essential in order to accurately forecast coastal flooding hazard in environments where wave conditions frequently exceed 1 m H_s (EurOtop, 2016), such as the southwest of the UK. An operational, real-time coastal flood warning system for southwest England, 'SWEEP-OWWL', has been developed that, for the first time, is capable of predicting wave runup elevation and overtopping volumes along the varied and embayed southwest coastline.

Forecasting wave runup and overtopping in southwest England requires a multi-pronged approach, as coastal defence in the region is provided by both natural defences (such as sandy beaches, gravel beaches, and dunes) and engineered defences (such as vertical seawalls, rock revetments, and sloping embankments). As current process-based models (for example XBeach) have not yet been developed and validated for the prediction of wave overtopping for all of the above profile types, and would be too computationally expensive to run operationally for a region as large as the southwest, a suite of empirical equations that predict wave runup elevation and overtopping discharge were used to forecast coastal flooding hazard.

SWEEP-OWWL has a 1 km Delft3D wave and hydrodynamic model at its core. The 1 km resolution is sufficient to resolve wave conditions within all but the very smallest embayments in the southwest. The 1 km model is forced along four boundaries by 2D spectral wave data, water-levels, and currents, and the entire domain is forced with gridded wind and pressure data, all from larger 7 km resolution Met Office models. A routine was developed in Matlab which runs automatically every day and retrieves the latest Met Office forcing data from an FTP server, prepares all model input files, runs the Delft3D model, and generates a fresh one-day hindcast and three-day forecast, providing real-time predictions of inshore waves and water-levels up to three days ahead.

Topographic profiles (currently 186 in total), representing the most at risk areas of the ~900 km coastline of southwest UK, were used to quantify intertidal slope and the elevation of beaches, dunes, and engineered structures for the prediction of wave runup and overtopping. The measured coastal profiles allow for water depth, wave height, and freeboard at sea defence structures to be determined for the prediction of overtopping, as well as the beach gradient for the prediction of runup elevation.

Inshore wave conditions from the 1 km wave and water-level model are extracted at a number of depth contours so that the shallowest possible conditions can be extracted prior to wave breaking, a process that would not be sufficiently resolved at 1 km resolution. The unbroken, nearshore wave conditions are then shoaled from the Delft3D output contour to the point of

incipient breaking using an empirical equation (van Rijn, 2014) which estimates breaking wave height, depth, and direction using linear wave theory and Snell's law for refraction.

Wave setup is estimated and added to the water-level within the surfzone to predict the still water-level at the coast at a given point in time, providing a corrected water depth with which to predict the depth-limited surf zone roller height across each coastal profile. Wave runup elevation is predicted using either the Stockdon *et al.* (2006) or Poate *et al.* (2016) formulae for sandy beaches and gravel beaches, respectively.

Having forecasted the wave conditions at the coast, wave overtopping hazard is predicted in a number of ways. For engineered sea defences, wave and water-level conditions are extracted at the toe of the defence, and the measured elevation and geometry of the structure is used to generate a prediction of average overtopping discharge (l/s/m) using the empirical equations described in the EurOtop II manual (EurOtop, 2016). The predicted discharge volume is then converted to a hazard level, from 1-4, using the tolerable overtopping thresholds from the EurOtop II manual.

For natural coastal profiles that do not feature a sea-defence structure, and some scenarios where a sea-defence is present but fully emergent and above the still water-level, wave overtopping hazard is poorly understood. To predict flooding hazard for such cases, the Total Water Level (still water-level plus wave runup elevation) was compared to the elevation of the natural or engineered defences, and an objective thresholding was used to relate the relative elevation to the four hazard levels.

Paragraph on the validation results

The empirical approach used in SWEEP-OWWL is highly computationally efficient. The prediction and plotting of coastal flooding hazard for all 186 profiles in the current database takes less than 20 minutes using a single computational core, once inshore wave conditions have been predicted (total modelling time is ~3 hours).

Although the SWEEP-OWWL model was developed as an operational forecast, it can also be used for strategic purposes, for example, to investigate the effects of climate change on coastal flooding hazard into the future. For example, the region and sub-region maps can be used to quickly identify potential flooding hotspots now and in the future.

UNIVERSITY OF PLYMOUTH

sweep
Applying research to benefit our environment and economy

Contents

Table of Figures

1. Introduction

An operational, real-time coastal flood warning system for southwest England has been developed as part of the South West Partnership for Environment and Economic Prosperity (SWEEP) project, funded by the UK's Natural Environment Research Council. The model is called the SWEEP Operational Wave and Water Level model (herein SWEEP-OWWL). Current coastal flood warnings for the region consider forecasted tide and storm surge levels, but do not objectively predict the level of wave runup and wave set-up, which can contribute many meters to the total elevation of the sea, especially on gravel beaches, and cause significant overtopping induced flooding during a storm. The developed system is capable of predicting wave runup elevation and overtopping volumes along the unique, macrotidal southwest coastline, which features embayed, sandy, gravel, and engineered regions.

The UK's Environment Agency (EA) and Met Office (MO) have partnered with SWEEP, and have assisted in the development and validation of the coastal flood warning system, in order to maximize the value gained from it. The primary form of output from the SWEEP-OWWL forecast is a prediction of coastal flooding hazard which is disseminated to the EA as a PDF via an automated email. The daily coastal flood email provides an overview of the southwest region, indicating any areas where coastal flooding is forecasted over the proceeding 3 days. For each area where flooding is forecasted, an individual PDF is provided which gives further detail on the timing and exact locations where flooding is likely to occur. The outputs of SWEEP-OWWL are discussed further in Section 3.

Forecasting wave runup and overtopping in southwest England requires a multi-pronged approach, as coastal defence in the region is provided by both natural defences (such as sandy beaches, gravel beaches, and dunes) and engineered defences (such as vertical seawalls, rock revetments, and sloping embankments). In most places, the coast is defended by a combination of these profile types, adding to the complexity of forecasting coastal flooding. Process-based numerical models provide an excellent means of predicting waves and hydrodynamics around the coast, and Delft3D is used in the SWEEP-OWWL model for this purpose. However, such models are not yet developed and validated for the prediction of wave overtopping of engineered defences. Even the model XBeach (Roelvink *et al.*, 2010), which has established itself as the industry standard model for simulating the effects of storms on beaches, is not capable of replicating wave overtopping of engineered structures, and, regardless, would be prohibitively computationally expensive to run for the entire ~900 km coastline of southwest England. As such, an empirical approach to predicting wave runup and overtopping has been taken for the SWEEP-OWWL forecast, allowing flood forecasts to be generated quickly on a regional scale. This approach uses a suite of empirical equations from the peer-reviewed literature to predict wave runup, setup and overtopping, and includes equations developed for sandy beaches (Stockdon *et al.*, 2006), gravel beaches (Poate *et al.*, 2016), and engineered sea defences (EurOtop, 2016).

To achieve an accurate prediction of wave runup, setup, and overtopping discharge, it is first necessary to resolve inshore wave conditions within each embayment in southwest England. This has not been achieved in existing flood forecasts, as wave conditions provided to the EA by the Met Office have been simulated using a 7 km resolution wave model, which for small to medium sized embayments cannot differentiate wave conditions on either side of a headland, despite significant wave sheltering often occurring. To resolve this issue, SWEEP-OWWL has a 1 km Delft3D wave and hydrodynamic model at its core. The 1 km resolution is sufficient to resolve wave conditions within all but the very smallest embayments in the southwest. This model then feeds the required hydrodynamic information to the inshore wave overtopping module, which predicts wave runup and overtopping at various locations around the coast.

2. Methodology

The SWEEP-OWWL coastal flood forecast is generated across three main stages (Figure 2-1). Firstly, wave and water-level conditions around the coast of southwest England are forecasted using a 1 km resolution coupled wave and hydrodynamic model, which takes forcing data from a coarser 7 km Met Office model and propagates the forecasted waves and water-levels in to the coast. The next stage involves using the inshore wave conditions to predict wave runup elevation and overtopping volume through the use of an extensive database of measured coastal profile data, and subsequently relating these predictions to a level of coastal flooding hazard. Thirdly, the predicted flooding hazard is presented in synoptic regional and sub-region maps as well as detailed time-series plots for each coastal profile over the forecast window. More detail on each of the steps involved is provided in Sections 2.1 to 2.5 below. The key steps involved in generating a prediction of flood hazard are summarized in the flow diagram in Figure 2-1.

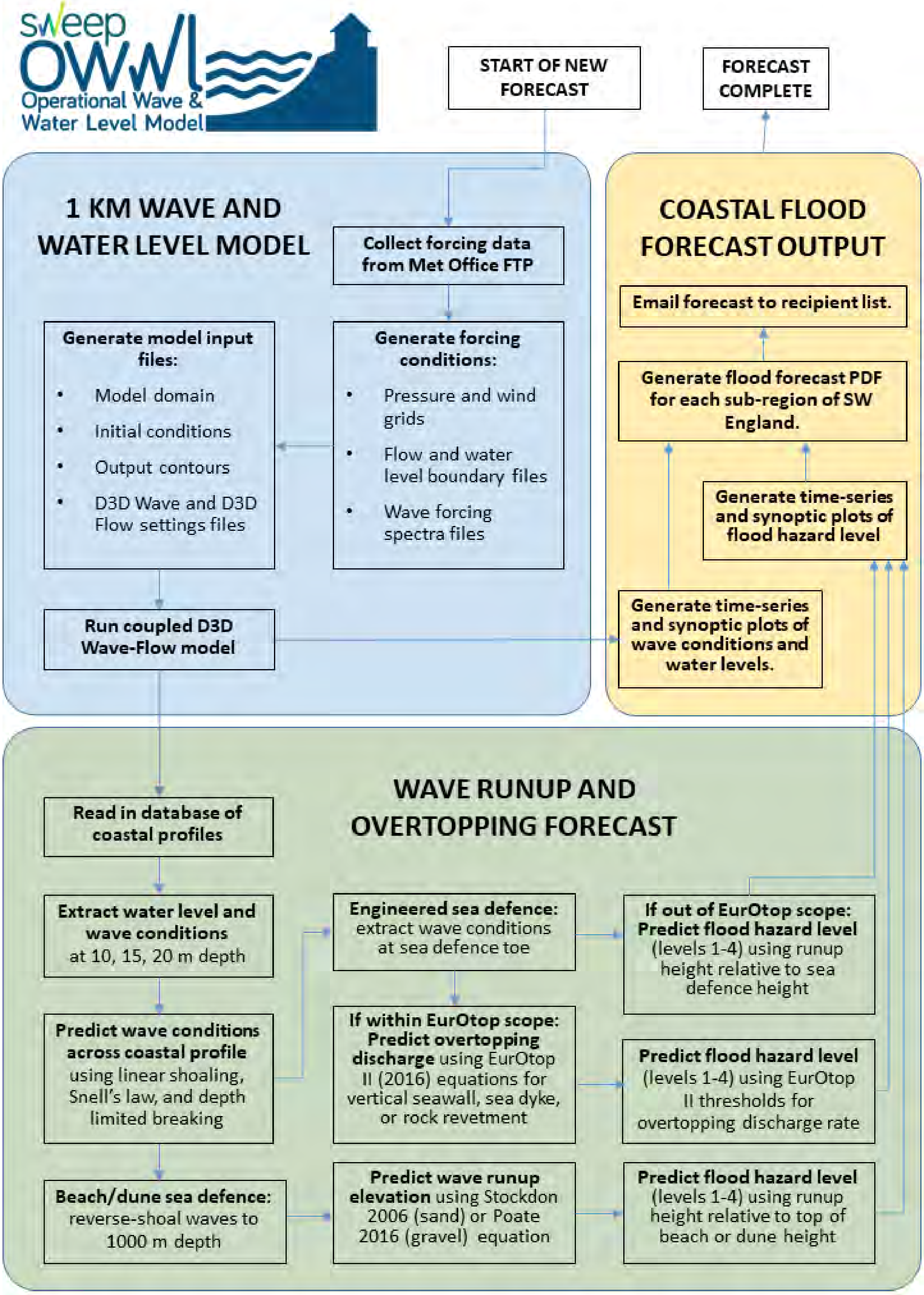


Figure 2-1. SWEEP-OWWL flow diagram describing the main stages of generating a wave and water-level simulation, predicting wave runup and overtopping, and outputting a coastal flood forecast.

2.1. Predicting wave conditions and water-levels

A coupled, 1-km resolution wave and hydrodynamic model was developed in Delft3D for the southwest of the UK. The primary purpose of this core model is to take offshore waves, water-levels and currents, and propagate them in to the coast using a high-resolution model grid, thereby resolving the hydrodynamics at a sufficient resolution to differentiate the conditions occurring within each embayment around the southwest coastline. The model domain was generated using European Marine Observation and Data Network bathymetry at approximately 250 m resolution (http://www.emodnet-bathymetry.eu/) which was interpolated to a rectilinear 1 km Delft3D model grid.

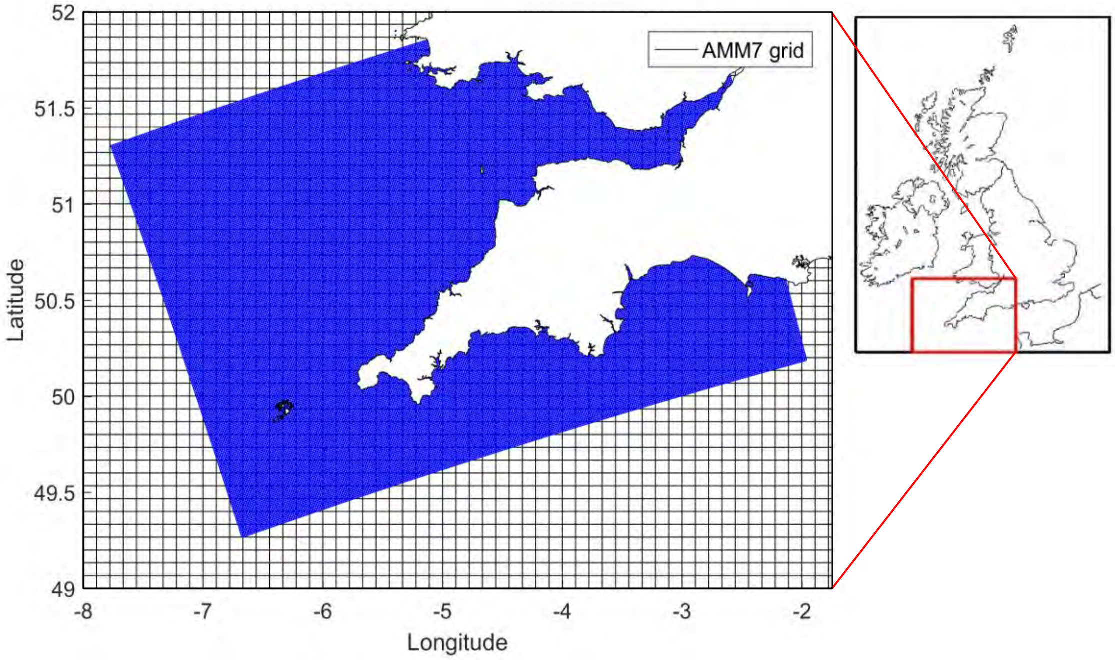


Figure 2-2. SWEEP-OWWL model domain (blue shaded area) and NEMO/WWIII Met Office forcing nodes (gridded lines). The inset map shows the location of the SWEEP-OWWL domain in the UK.

The Delft3D model consists of two modules, one that computes water-levels and currents ('D3D-flow'), and one that propagates waves ('SWAN'), and these modules communicate with one another to allow the currents to influence the development of waves in the model, and vice versa. This core model is driven by larger 7 km resolution NEMO (AMM7) and WWIII Met Office models (Figure 2-2), which provide 2D spectral wave data, water-levels, and currents to drive the four model boundaries, as well as gridded wind and pressure data across the entire domain to allow wind wave growth and barometric effects within the SWEEP-OWWL model. A routine was developed in Matlab which runs automatically every day and retrieves the latest Met Office forcing data from an FTP server, prepares all model input files, runs the Delft3D model, and generates a fresh one-day hindcast and three-day forecast, providing real-time predictions of inshore waves and water-levels up to three days ahead. The hindcast predictions are used to provide a near real-time comparison of the model output to real wave and water-level conditions at the coast, observed using the Channel Coastal Observatory (herein CCO; www.channelcoast.org) network of wave buoys and tide gauges (Figure 2-3**Error! Reference source not found.**).

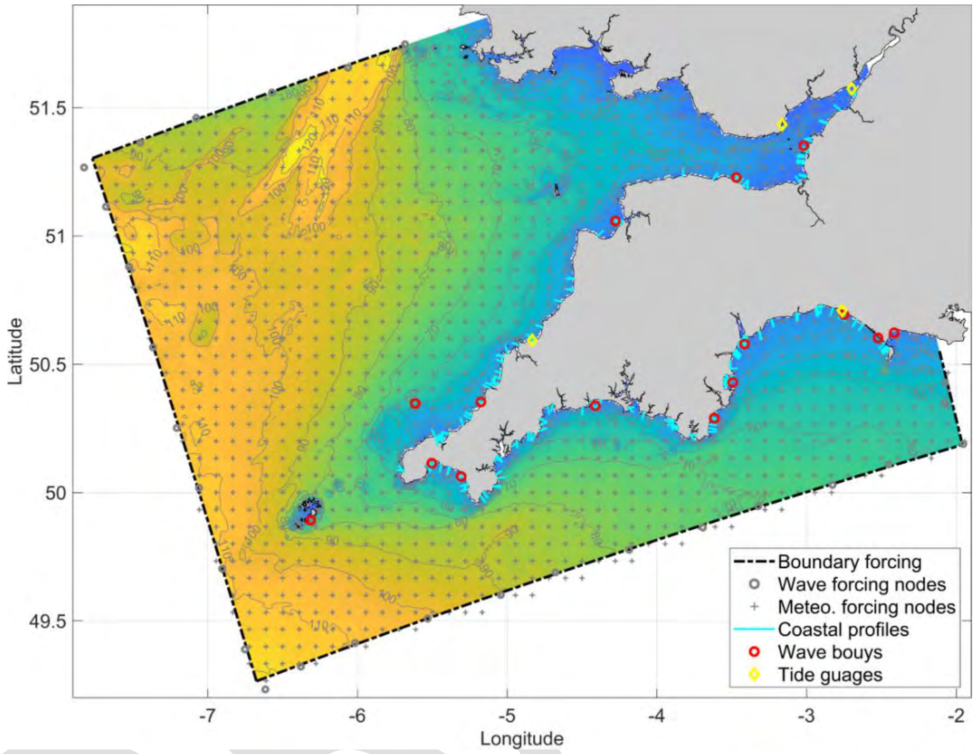


Figure 2-3. SWEEP-OWWL Delft3D model domain, with bathymetric depth shown by shaded and labelled depth contours (m ODN). The location of wave buoys (circles), tide gauges (diamonds) and coastal profiles (lines, length exaggerated) are shown, and forced boundaries are indicated along the sides of the model domain.

Having shoaled the waves from the model boundary in to shallow water at the coast, wave and water-level conditions are output along the 10, 15, and 20 m depth contours at approximately 1 km spacing, providing inshore conditions in each embayment along the coastline. Output is selected from one of the 10, 15, or 20 m depth contours by using the shallowest contour at which wave breaking is not occurring. Wave breaking in this instance is conservatively indicated by significant wave heights at the output location greater than half the water depth. Therefore, for wave conditions of up to 5 m H_s, output is taken from the 10 m depth contour, and for more extreme wave conditions the 15 or 20 m contours will be used. This approach enables the wave conditions to be extracted from the model as close to the coast as possible, but before the point of breaking, a process which the 1 km model grid would not sufficiently resolve.

The importance of outputting wave conditions at the shallowest possible contour prior to breaking is demonstrated in Figure 2-4**Error! Reference source not found.**, where a wave shadow caused by obliquely arriving waves entering the Torbay embayment (circled) causes a significant drop in wave height between the 10 m and 15 m depth contours. If wave conditions were taken at 15 m depth, the estimated wave height at the coast is likely to be considerably overpredicted in this example. This also provides further justification for the fine-resolution wave model used in SWEEP-OWWL, as differentiating the output at such depths would not be possible using a model grid size that is significantly coarser than 1 km. Model grids on the order of 7 km resolution (as per previous forecasts) would not be able to differentiate the wave conditions at different locations within the circled embayment.

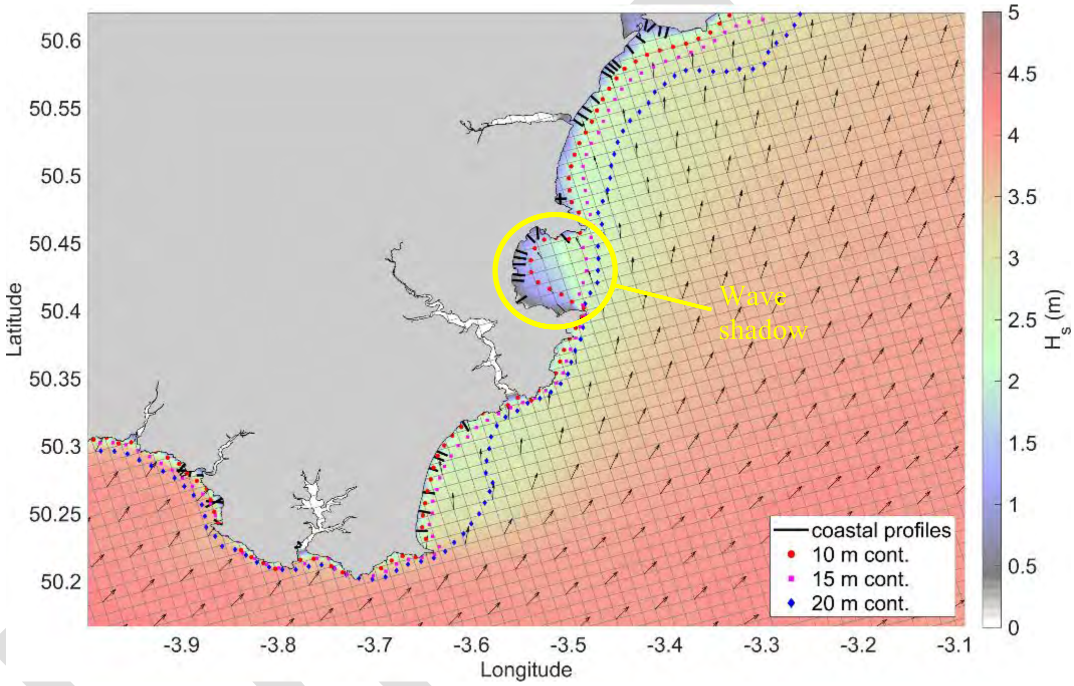


Figure 2-4. Example output locations from the 10 m, 15 m and 20 m depth contours along the South Devon coastline. Colour indicates wave height under an example storm wave condition, with wave direction vectors shown on every 4th model node. The circled area demonstrates wave shadowing occurring due waves arriving obliquely at the Torbay embayment, and a wave height gradient occurring between two potential output depths (dotted contours).

The unbroken, nearshore wave conditions are shoaled from the Delft3D model output contour to the point of incipient breaking using an empirical equation (van Rijn, 2014) which estimates breaking wave height, depth and direction using linear wave theory and Snell's law for refraction. This approximation of the breaking wave conditions considers conservation of energy, depth-induced wave breaking, and the refraction of oblique waves, but does not include energy losses through bed friction or white capping, which are assumed to be small between the output contour and the surfzone. A breaker criterion, γ, that varies with beach slope (Masselink and Hegge, 1995) was used to define the depth at which wave breaking occurs, and to define the depth-limited roller height within the surf zone. Significant wave height, H_s, can then be estimated at any point between the model output contour and the shore; first by interpolating wave height between the model output depth and breaking depth, and then within the surfzone using γ and the water depth over the measured local profile (see Section 2.2). Wave setup – the time-averaged super-elevation of the sea surface within the surf zone, caused by water accumulating at the shore after wave breaking – is estimated using the deepwater wave height, peak wave period, and beach slope, according to the formula of Holman and Sallenger (1985). Wave setup is then added to the water-level within the surfzone to predict the still water-level at the coast at a given point in time, providing a corrected water depth with which to predict the wave roller height across the beach profile.

Having estimated the wave conditions at the coast, wave height is then predicted at the toe of a sea defence structure, if present, by extracting the wave height at the cross-shore location of the sea defence toe (Figure 2-5). If the sea defence is within the surfzone, then the wave height is entirely determined by the still water depth at the toe of the defence. If waves have not yet broken when they reach the sea defence, then the wave height at the toe is determined through linear interpolation, as previously described. Once wave conditions at the toe of the defence have been defined, it is possible to apply the various formulae for predicting wave overtopping discharge from the EurOtop Manual (Section 2.4).

For the prediction of wave runup elevation, a different approach is required to that used for wave overtopping, as the runup equations require input of deepwater, rather than nearshore, wave conditions. To satisfy this need, the previously determined breaking wave conditions are reverse-shoaled to a depth of 1000 m using linear wave theory. This ensures that the wave conditions that are passed to the equations have undergone all major refraction and shoaling effects before the equivalent deepwater conditions are calculated, otherwise use of the 'raw' offshore wave conditions would overestimate wave height in the case of sheltered embayments. Wave runup elevation, and the potential for overtopping of natural (un-engineered) coastal profiles, is then predicted using the formulae described in Section 2.3.

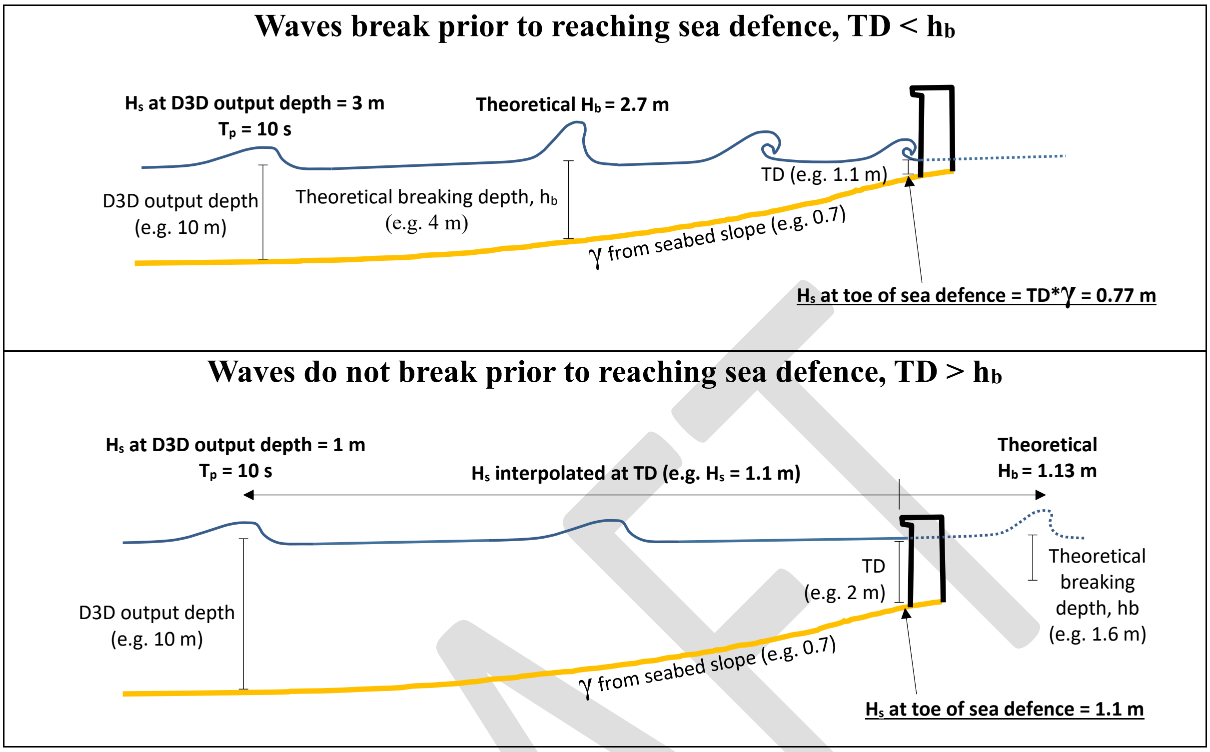


Figure 2-5. Method for propagating significant wave height (H_s) from Delft3D (D3D) output location to the toe of sea defence when waves have broken prior to reaching the sea defence (upper panel), and when waves have not broken prior to reaching the sea defence (lower panel), for example wave conditions of 3 m and 1 m H_s (upper and lower panels, respectively). Breaking wave height (H_b) and depth (h_b) are calculated using the formula of van Rijn (2014) and the breaker criterion γ is calculated from the beach slope using the formula of Masselink and Hegge (1995).

2.2. Database of coastal profiles

A database of 186 topographic profiles (Figure 2-3), representing the most at risk locations across 112 towns and beaches along the ~900 km coastline of southwest UK, was collated. These profiles are used to quantify intertidal slope and the elevation of beaches, dunes, and engineered structures for the prediction of wave runup and overtopping. The profiles are measured down to Mean Low Water Spring elevation at least bi-annually by the Plymouth Coastal Observatory (PCO), and can therefore easily be updated as new data are collected.

As the PCO archive contains profile data every 50 m along the coast in most locations, only a selection of profiles were chosen from their archive. For each coastal location, one or more profiles were selected based on the type of sea defence present (natural or man-made), the amount of urbanization at risk, as well as the frequency of data collection at that profile (some are measured bi-annually, while others are measured every 5 years). If multiple profiles existed in an urbanized location and shared a common sea defence type with the same crest elevation, then only the profile with the most frequently updated profile measurements was selected for inclusion in the database. Conversely, in locations where differing levels of coastal defence or wave exposure exist, multiple coastal profiles may have been included for a single town or village.

In addition to the profile elevation data, a number of additional pieces of information were collated from the CCO archive, or were manually gathered from LiDAR data or freely available imagery for each profile. These include:

- Profile coordinates
- Profile orientation
- Feature codes (sea defence, sand, gravel, rock, etc)
- Sea defence type, if present (vertical seawall, embankment, rubble mound)
- Minimum dune crest elevation within 500 m of the profile (from PCO LiDAR data)
- Minimum sea defence elevation within 500 m of the profile (from PCO LiDAR data and topographic profiles)
- Presence of a wave return lip ('bull nose'), if a sea defence profile
- Presence and elevation of any significant toe reinforcements ('toe mound'), if a sea defence profile

It was important to manually determine from LiDAR data the minimum dune crest elevation for naturally defended coastal profiles, and the sea-defence elevation for engineered coastal profiles. The minimum dune elevation is of importance, as it determines the elevation wave runup needs to reach before overtopping of the natural defence begins to occur. The measured PCO profiles often do not coincide with the lowest point of the dune crest, so in some cases would otherwise overestimate the dune height. For some engineered coastal profiles, the topographic measurements made by PCO cannot measure the entire profile to the crest elevation, for example where restricted access exists at the train line in Dawlish, south Devon. In these cases, the crest elevation was determined from LiDAR data, to ensure that the sea defence elevation was not underestimated by an incomplete topographic profile.

Although most coastal towns in the southwest are represented by at least one profile in the database, the list of profiles is not yet exhaustive. Coastal flooding is currently predicted in all areas where PCO topographic data are available, representing nearly all of the urbanized coastal areas in southwest England. However, some areas could not be forecasted accurately at this stage and have not yet been included in the profile database. In particular, north Devon does not have any PCO monitored topographic profiles, and the Isles of Scilly are not resolved adequately by the Delft3D model to generate a forecast there. However, these regions could be added in future (see Section 5).

2.3. Predicting wave runup elevation

As all of the studied coastal profiles include some form of intertidal beach slope, the wave runup elevation on the beach can be predicted using an empirical equation. Although wave overtopping discharge cannot be determined from the runup elevation alone, the runup elevation provides vital information about the likelihood of natural coastal profiles (un-engineered beaches and dunes) being overtopped, for which there does not exist any empirical means to predict overtopping discharge. The runup height, $R_{2\%}$, represents the elevation exceeded by only 2% of swash waves running up the beach face, and includes the contribution from wave setup (the time-averaged super-elevation of the sea caused by wave breaking at the coast), and wave runup (the time-varying excursion of individual swash waves running up the beach). These processes are primarily governed by the relative magnitudes of the beach slope and the offshore wave steepness (Stockdon *et al.*, 2006).

For sandy beaches, the formula of Stockdon *et al.* (2006), which was determined through 10 dynamically different field experiments conducted at full scale on 6 sandy beaches in Holland and the USA, is used to predict wave runup elevation. The Stockdon runup equation has nominal bias and root-mean-square error magnitudes of 17 cm and 38 cm, respectively (Stockdon *et al.*, 2006). For gravel beach profiles, the formula of Poate *et al.* (2016) was used, which was developed from 10 different full-scale field experiments at 6 field sites in the UK featuring sediments ranging from fine gravel to large pebbles. Poate *et al.* (2016) also tested and expanded the range of application of their formula using complimentary synthetic runup data from a validated XBeach numerical model. The Poate runup equation has nominal bias and r-squared values of -0.07 cm and 0.87, respectively (Poate *et al.*, 2016).

Using the reverse-shoaled values of deepwater wave height (Section 2.1), the wave runup elevation at the coast, $R_{2\%}$, is predicted over the forecast window and added to the predicted still water-level to enable a forecast of the Total Water Level (still water-level plus runup) through time. Wave runup was used to estimate coastal flood hazard for naturally defended coasts, by comparing the runup elevation to the lowest elevation of the dune or barrier crest. The runup elevation was used in a similar way to predict flood hazard at sea defence structures for cases where the still water-level has not yet reached the toe of the sea defence. Both scenarios as described in more detail in Section 2.5.

2.4. Predicting wave overtopping discharge

For coastal profiles that feature a sea defence structure, the average volume of water overtopping the sea defence per second (the 'overtopping discharge') is predicted using the formulae contained in the EurOtop II manual (EurOtop, 2016). The second edition of the manual was published in 2016 and features the latest in overtopping methods and equations. All of the equations used in EurOtop II to predict overtopping discharge were determined through scaled and prototype-scale physical modelling of sea defences under wave attack, and EurOtop's 'mean value approach' is used in SWEEP-OWWL to predict overtopping discharge based on the best fit to each experimental dataset. EurOtop II contains a large number of overtopping equations for use in different situations, including equations for embankments (sea dykes), rock revetments, and vertical seawalls, and a multitude of equations for each structure type depending on the environmental conditions that are prevailing. These equations were coded into the SWEEP-OWWL model, using a decision-tree process to determine which of the many equations is to be used for a given profile at a given point in time.

Each equation predicts the volume (litres) of water overtopping each meter of sea defence, per second, $Q,$ and is therefore an estimate of the average discharge rate. In reality, overtopping is an episodic rather than continuous process, where the majority of water overtopped in a given minute may occur during a small number of waves, rather than continuously, as is suggested by the average discharge rate. Regardless, the continuous discharge rate is associated with tolerable overtopping rates for people, property, and vehicles (in addition to sea vessels and engineered structures) in the EurOtop II manual, making it an applicable metric to the prediction of coastal flooding hazard.

As some of the factors in the EurOtop II manual require site-specific knowledge of sea defence design features (for example the roughness elements on an embankment), not all of the factors that are currently parameterized in the EurOtop II manual could be determined from a desktop assessment of each coastal profile. As such, it was not possible to include all of the available overtopping parameters in the SWEEP-OWWL model, meaning that at some sites the representation of the sea-defence is a (usually conservative) simplification of the real situation. The factors from EurOtop II that are accounted for in the SWEEP-OWWL model are:

- impulsive or non-impulsive wave breaking (vertical seawalls)
- the presence or absence of an influencing foreshore (vertical seawalls)
- low or high relative freeboard (vertical seawalls)
- large toe mounds/reinforcements (vertical seawalls)
- wave return lip fixed influence factor (vertical seawalls)
- parapet fixed influence factor (vertical seawalls)
- rock roughness fixed influence factor (rock revetments)
- obliquely-arriving waves (vertical seawalls, embankments, and rock revetments)
- a storm wall at the top of the structure (embankments, and rock revetments)

The factors from EurOtop that are not accounted for in the SWEEP-OWWL model are:

- perforated seawalls (vertical seawalls)
- crest width (rock revetments)

- berms or promenades (embankments)
- currents (vertical seawalls, embankments, and rock revetments)
- site-specific surface roughness (embankments and rock revetments)
- site-specific wave return lip or parapet influence factor (vertical seawalls)
- reshaping berm breakwaters (rock revetments)

In addition, two important overtopping situations are not yet well understood in the literature, and were therefore either fully or partially omitted from the SWEEP-OWWL model. These situations are:

a) when strong wind affects overtopping

b) overtopping of a vertical sea wall or rock revetment with an emergent (i.e. above still water-level) toe

Situation (a) is thought to potentially increase wave overtopping, especially during impulsive wave breaking at a sea defence, by up to a factor of 4 (EurOtop, 2016). However, there is considerably uncertainty in these estimates due to the difficulty of scaling wind effects from small-scale experiments in the literature, and it is believed that the enhancement of overtopping due to wind is likely to be considerably less than this in reality (EurOtop, 2016). In tests of the SWEEP-OWWL model, a wind enhancement factor of two was found to produce unrealistically high overtopping volumes in many cases. Situation (a) is therefore not accounted for in SWEEP-OWWL and the influence of wind is ignored.

There has been limited investigation of situation (b) in the literature to date. EurOtop II does include formulae that describe wave overtopping of embankments with a shallow foreshore and an emergent toe, as the foreshore slope can be combined with that of the embankment, enabling prediction of overtopping using the 'effective slope' of the combined foreshore and embankment (Altomare et al., 2016). Overtopping of embankments with an emergent toe is therefore predicted by SWEEP-OWWL. The equivalent situation for rock revetments does not appear to have been studied, and is therefore not predicted by SWEEP-OWWL. There are some empirical data to support an overtopping formula for a limited range of situations involving a vertical seawall with an emergent toe on a very steep (i.e., gravel) beach (Bruce et al., 2004; Bruce et al., 2010). As large runup elevations can occur, often more than twice the significant wave height (Poate *et al.*, 2016) on a gravel beach, it is highly possible for sea defences at the top of beaches to be overtopped when the toe elevation is above still water-level. Therefore, the available formulae described in Bruce *et al*. (2004) and Bruce *et al*. (2010) have been included in the SWEEP-OWWL model to predict wave overtopping on gravel beaches with an emergent sea defence toe.

For the remaining situations – i.e. overtopping events involving a rock revetment with an emergent toe, or a vertical seawall with an emergent toe on a sandy beach or shallow-sloping gravel beach – there is a lack of formulae with which to predict wave overtopping. As it could be misleading to have no overtopping prediction in these situations (which could be wrongly interpreted as overtopping hazard being zero) a different approach was used to generate an estimate of overtopping hazard. In such cases, the total water-level (still water-level plus wave runup elevation) was compared to the elevation of the sea defence, and estimated thresholds based on the relative elevations were applied to generate a coastal flooding hazard level (see Section 2.5).

2.5. Predicting coastal flood hazard level

There are three situations for which different approaches to predicting the coastal flooding hazard level have to be used, which are described in this section, and in Figure 2-6:

1. Overtopping of a sea defence structure, within the scope of EurOtop II
2. Overtopping of a sea defence structure, outside the scope of EurOtop II
3. Overtopping of a natural coastal profile, where no engineered sea defence is present

The hazard level for the first situation is relatively well understood, and the thresholds for tolerable overtopping rates provided in EurOtop II were applied to such cases. The hazard level for the second and third situation are not well understood, and there exists no published literature that can provide hazard thresholds for these situations. As it is desirable to have a consistent set of hazard levels that can be used for all scenarios, thresholds based on the Total Water Level (still water-level, plus wave runup) were developed for situations 2 and 3. The hazard thresholds used in SWEEP-OWWL are summarised in Table 1, and are described in more detail in the following paragraphs.

For coastal profiles featuring a sea defence structure where it has been possible to predict wave overtopping discharge (i.e., 'situation 1' above; see Section 2.4 for scenarios where this can and cannot be predicted by SWEEP-OWWL), the predicted discharge volume, Q (l/s/m), is converted to a hazard level using the thresholds described in Section 3.3 of the EurOtop II manual (EurOtop, 2016). The various tolerable overtopping rates for people, property, and vehicles were simplified into a monotonically increasing set of hazard levels by aggregating the discharge thresholds for waves > 3 m H_s, and extending their application to all wave conditions > 1 m H_s (where H_s is taken at the toe of the sea defence structure). For waves of 1 – 3 m H_s, EurOtop II provides considerably higher tolerable overtopping thresholds, as smaller waves can deliver less maximum overtopping volume in a single wave and therefore potentially pose less of a hazard. Increased overtopping thresholds for waves between 1 – 3 m H_s were tested in the SWEEP-OWWL model during the model validation stages, but it was found that overtopping hazard was often under-predicted using these higher hazard thresholds. Therefore, the more conservative thresholds for waves with H_s > 3 m (which regularly occur during storms in the southwest) were applied to all wave conditions > 1 m H_s. EurOtop II suggests that all overtopping where H_s < 1 m is 'tolerable', and therefore the lowest hazard level (level 1) is assigned for situations where H_s < 1 m. The exception to this is if the freeboard (height from still water-level to sea defence crest) is < 1 m, in which case a hazard level greater than 1 can be predicted as significant overtopping or even weir flow conditions can occur as freeboard approaches zero. The hazard thresholds used in SWEEP-OWWL for overtopping of a sea defence are provided in column 3 of Table 1.

For beaches where there is a sea defence structure, but a prediction of wave overtopping could not be made because the sea defence was completely above the still water-level and on a shallow sloping beach (see Section 2.4) – i.e., 'situation 2' above – hazard thresholds were developed based on the Total Water Level compared to the height of the sea defence structure. These thresholds are provided in column 4 of Table 1. A 'ball park' calibration of these thresholds was performed using a hypothetical storm event, where the toe of a sea defence structure was sequentially emergent (out of scope of EurOtop II) then submerged (within scope of EurOtop II) during a rising tide under constant wave conditions. The thresholds were varied until a smooth transition in hazard level was achieved between the time when the sea defence was emergent and submerged, under the assumption that the hazard level should steadily increase as the tide rises.

For beaches where there is no sea defence structure, and the primary line of coastal defence is provided by a beach, dune, or barrier (i.e., 'situation 3' above), the hazard level is estimated by comparing the predicted Total Water Level (still water-level plus runup) to the height of the lowest point of the dune crest within 500 m of the profile (if a dune is present), or the elevation of the top of the measured beach profile (if a dune is not present). These thresholds are provided in column 5 of Table 1. 'Ball park' calibration of these thresholds was performed using data from Storm Eleanor (3rd January 2018) and Storm Emma (2nd March 2018). During Storm Eleanor wave overtopping occurred at the sandy and exposed Perranporth beach in north Cornwall. During the storm, the total water-level reached 0.6 m above the top of the beach profile and caused flooding of the beach car park and nearby businesses and properties; the storm therefore posed a hazard to pedestrians and property ('level 3'). Storm Emma was very extreme for an easterly storm (return period of 50 – 100 years), and significant overtopping of the gravel barrier occurred at Slapton Sands beach in south Devon, sufficient to destroy one lane of the A379 road that sits atop the barrier. The Total Water Level during Emma reached 0.9 m above the barrier crest, and clearly this overtopping would have posed a hazard to pedestrians, property, and vehicles, had they been present behind the barrier ('level 4'). These two storms provide a very simplistic means with which to determine ball-park thresholds for flooding hazard level using only knowledge of the Total Water Level and beach elevations, and ideally in future a more objective and precise means with which to determine such hazard levels will be available.

Table 1. Description of coastal flooding hazard levels used in SWEEP-OWWL. Q is average overtopping discharge in l/s/m, H_s is significant wave height at the toe of the sea defence in m, FB is the freeboard in m (difference in elevation between still water-level and the sea defence crest elevation), TWL is the Total Water Level in m (still water-level plus runup height), SD is the sea defence height in m (e.g. 1/2 SD = runup reaching an elevation half way up the sea defence), ND is the natural defence (beach, dune, or barrier) crest elevation in m (e.g. ND + 0.5 = runup reaching an elevation 0.5 m higher than the dune crest).

SWEEP-OWWL Hazard level	**Description of hazard level**	**Discharge rate** (sea defences within scope of EurOtop)	**Wave runup** (sea defences out of scope of EurOtop)	**Wave runup** (naturally defended beach)
1	low risk of overtopping	$0.0 \leq Q < 0.3$ (or $H_s < 1$ and $FB > 1$)	TWL < ¼ SD	TWL < ND
2	risk to pedestrians	$0.3 \leq Q < 1.0$ ($H_s \geq 1$ and/or $FB < 1$)	¼ SD ≤ TWL < ½ SD	ND ≤ TWL < ND+0.5
3	risk to pedestrians & property	$1.0 \leq Q < 5.0$ ($H_s \geq 1$ and/or $FB < 1$)	½ SD ≤ TWL < SD	ND+0.5 ≤ TWL < ND+0.8
4	risk to pedestrians, property & vehicles	$5.0 \leq Q < \infty$ ($H_s \geq 1$ and/or $FB < 1$)	SD ≤ TWL	ND+0.8 ≤ TWL

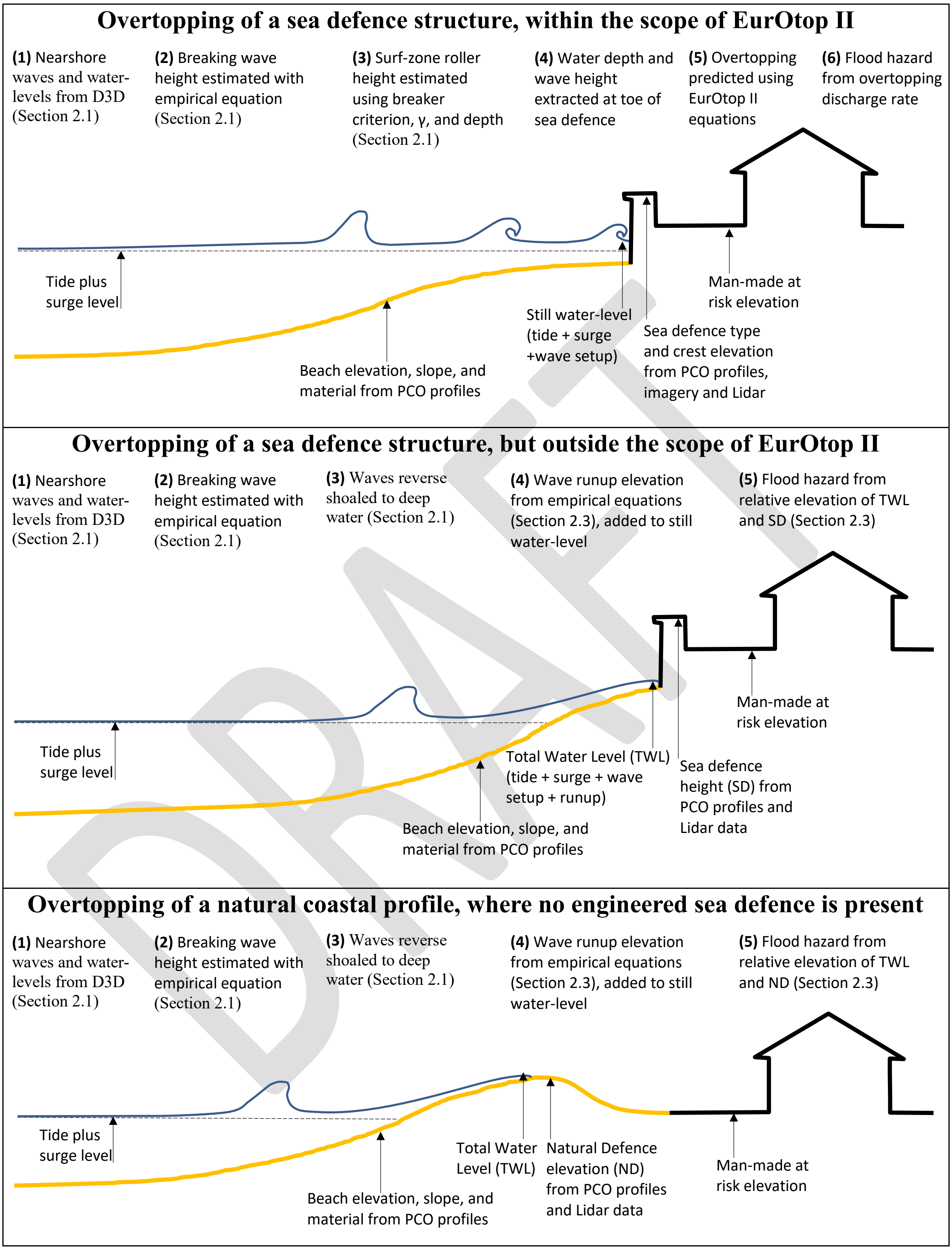


Figure 2-6. Schematic of three different methods for predicting coastal flooding hazard

3. Model Output

The SWEEP-OWWL forecast consists of a PDF for each of 25 geographical sub-regions around the southwest (Figure 3-1). Three forecast levels are provided in each PDF:

Level 1: Regional Overview plot of maximum flood risk in the proceeding 3 days
Level 2: Sub-Region Overview plot of maximum flood risk in the proceeding 3 days
Level 3: Individual Profile Forecast plots showing timing of predicted flooding

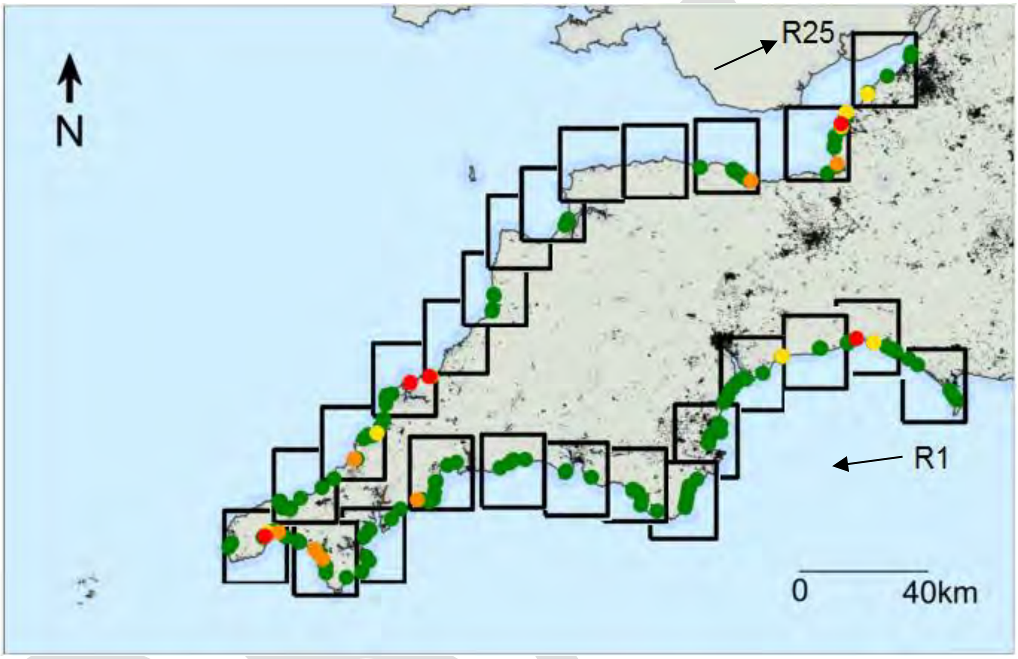


Figure 3-1. OWWL regional overview showing all of the 25 sub-regions. Region 1 is in the southeast and the regions are numbered clockwise around the peninsular.

An example of a full PDF forecast is given in Figure 3-2 and Appendix A. The format of the PDF is standardised to be consistent regardless of the forecast data/potential for flooding. At the top of page 1 is the date that the forecast was generated on and the date range for which it is valid. The first page of the PDF is comprised of the Level 1 Regional Overview Plot (Figure 3-3), the Level 2 Sub-Regional Overview (Figure 3-4) and the Sub-Regional Wave Forecast (Figure 3-5). The second page onwards consists of the Level 3 forecasts for individual profile (Figure 3-6), with the number of plots reflecting the number of profiles within the sub-region. PDFs for any sub-regions where level 2 – 4 flood hazard (Table 1) is forecasted are attached to the automated OWWL coastal flood warning email, unless a user subscribes to specific sub-regions, in which case the PDFs for those sub-regions will be attached.

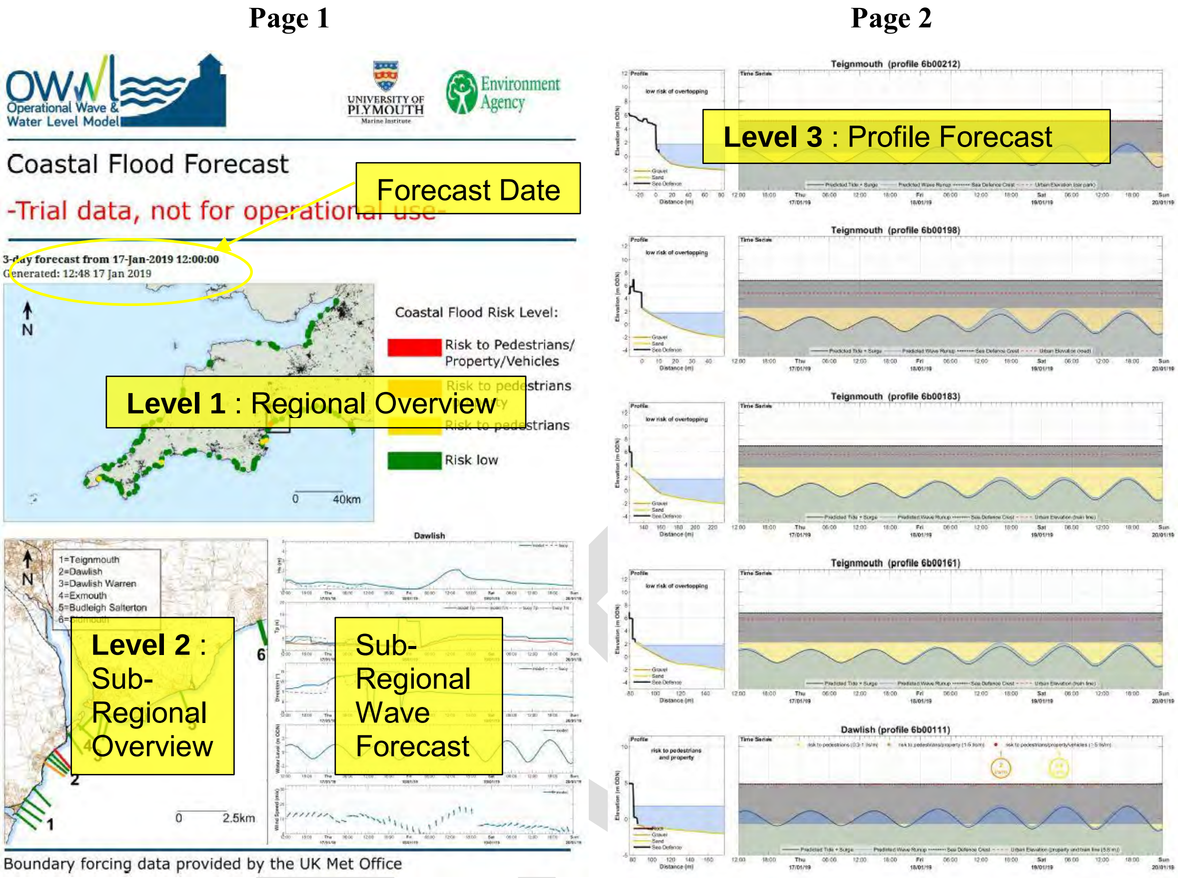


Figure 3-2. Example of the OWWL forecast PDF; Page 1 (left panel) and subsequent pages (right panel). Annotation in yellow identifies the key makeup of the PDF and is discussed further in the text.

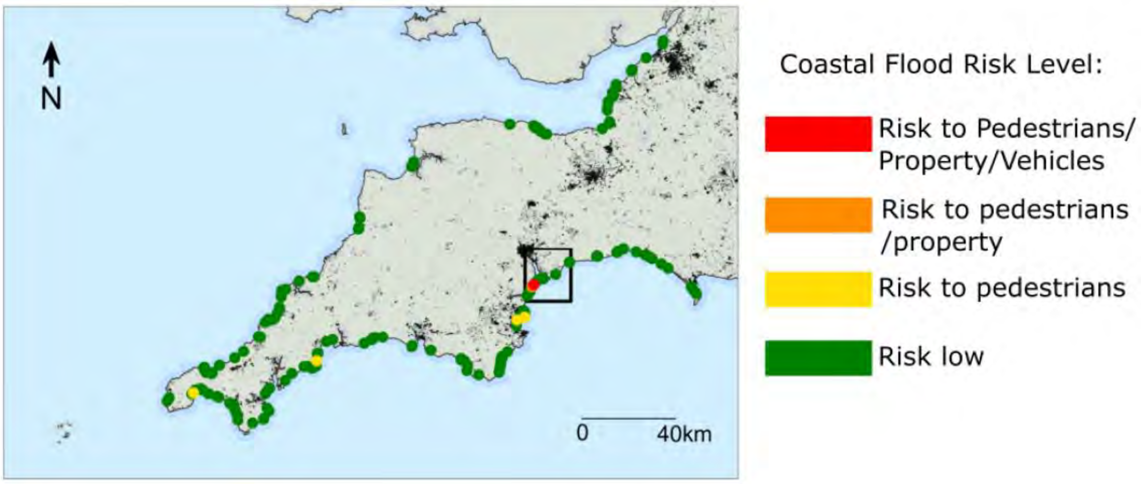


Figure 3-3. Example of Level 1 Regional Overview plot – summary of maximum flood risk in the proceeding 3 days, and flood risk colour scale.

The Level 1 Regional Overview plot (Figure 3-3) is intended to provide a large scale appraisal of possible coastal flood risk for the southwest. The figure presents data for 186 profiles around the region which are coloured based on the highest flood hazard level (Table 1) forecasted for the proceeding three days. This figure quickly reveals the areas that are most likely to experience flooding, as well as the predicted severity of the flooding. Because each sub-region is presented in a separate PDF, the Level 1 Regional Overview allows the user to identify which regions which may be of operational interest.

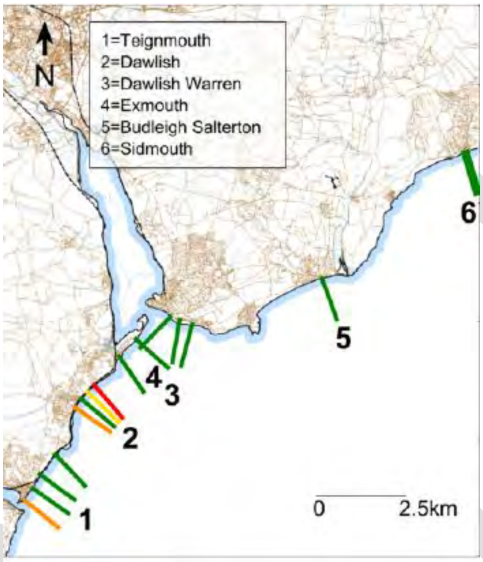


Figure 3-4. Example of Level 2 Sub-Region Overview plot – summary of maximum flood risk in the proceeding 3 days for specific profiles located within the geographical limits of the sub-region.

The Level 2 Sub-Region Overview plot (Figure 3-4) provides a more detailed view of the flooding hazard, showing each individual profile in the sub-region for which a forecast has been generated. Like Level 1, the colours reflect the maximum flood risk for the 3-day forecast period and not the daily flood risk. A numbering system is provided to help identify the main towns and villages within the sub-region. For each sub-region the most suitable wave forecast is provided (Figure 3-5). Where possible the forecasted waves are extracted where an existing CCO wave buoy is located, to provide a real-time validation against the previous day's hindcast predictions. The plots provide the hydrodynamic time-series over a three day forecast period, showing significant wave height (H_s), peak and mean wave period (T_p and T_m), peak wave direction, still water-level (which includes barometric effects), and wind speed and direction. Model predictions (solid lines) are compared to observed wave and tide conditions (dashed lines), where the model point is co-located to a CCO wave buoy, over a 12-hour hindcast period.

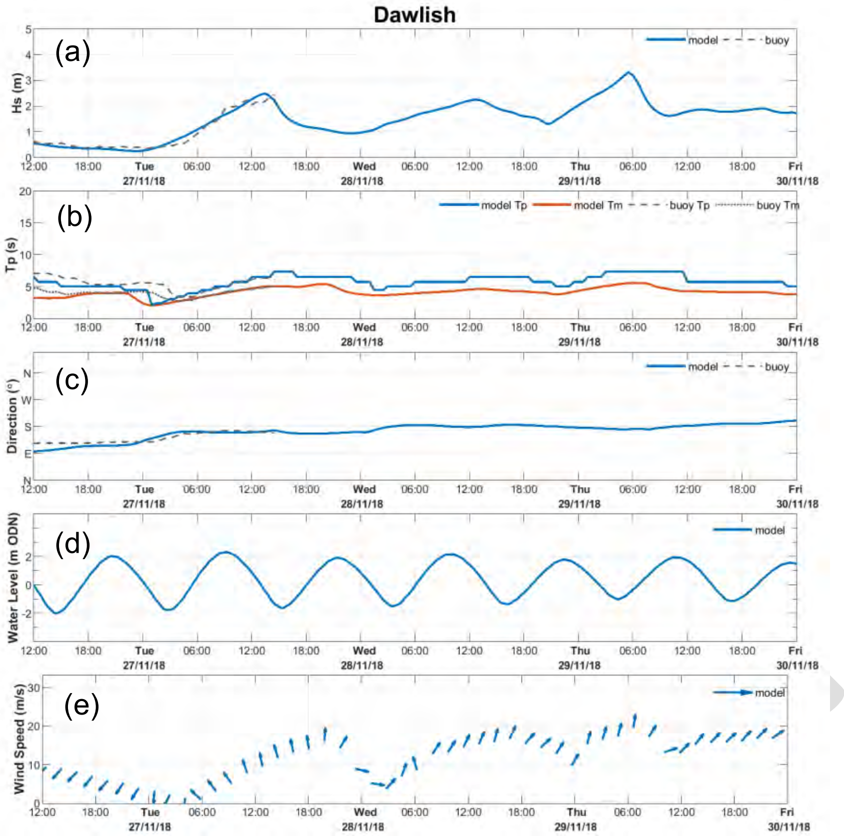


Figure 3-5. Example of sub-regional hydrodynamic time-series over a 12-hour hindcast, and three day forecast period, showing significant wave height (H_s, panel a), peak and mean wave period (T_p and T_m, respectively, panel b), peak wave direction (panel c), still water-level (panel d), and wind speed and direction (panel e). Model predictions (solid lines) are compared to observed wave and tide conditions (dashed lines) over the 12-hour hindcast period.

Page two, and subsequent pages of the PDF provide further granularity in the forecast (Level 3 Individual Profile Forecast plot). For each profile previously identified in the Level 2 Sub-Region Overview plot, a detailed flood forecast is provided (Figure 3-6), which is composed of two plots: on the left is the measured coastal profile for which the forecast is being made, including the composition of the profile e.g. sand, gravel or sea defence. On the right the forecasted water-levels and flood hazard for the preceding three days are presented. For clarity this is shown as predicted tide + barometric surge (still water-level; black line) and predicted Total Water Level (still water-level + wave runup elevation; blue line). The annotated plot in Figure 3-6 highlights the key features for interpretation. Note the difference between sandy/gravel beaches, and those with a sea defence; for sea defences the EurOtop II formula provides an overtopping discharge volume (in l/s/m) and associated hazard level, whereas naturally defended profiles just have the predicted hazard level, based on the thresholds given in Table 1.

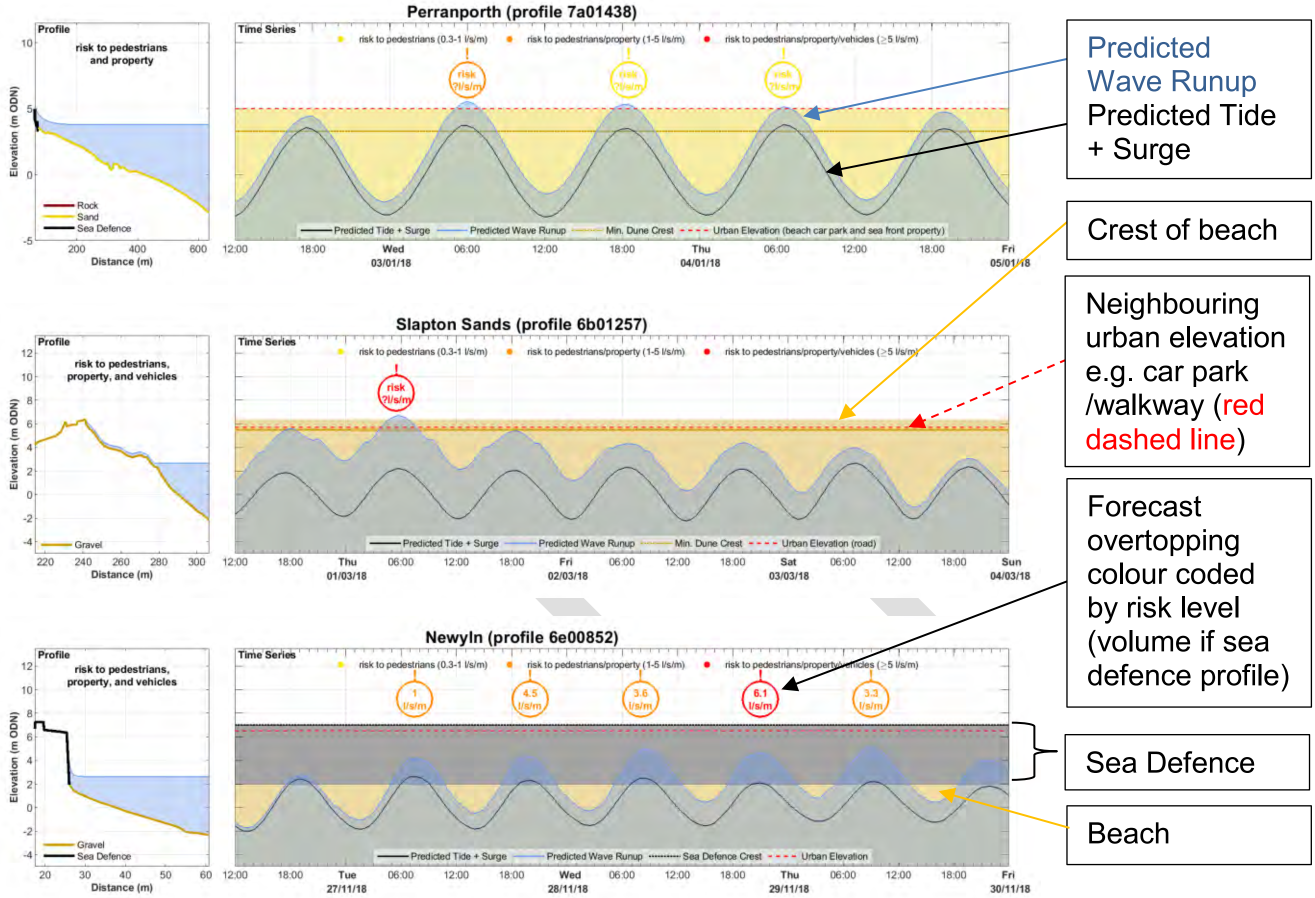


Figure 3-6. Examples of Level 3 Individual Profile Forecast plots, showing details of the timing and severity of predicted flooding for individual coastal profiles over the proceeding 3 days. Top panel: sandy beach profile; middle panel: gravel beach profile; bottom panel: engineered sea defence.

4. Model validation

SECTION TO BE ADDED AFTER THE MODEL VALIDATION PERIOD IS COMPLETED AT THE END OF MARCH

5. Future developments

Through development of the SWEEP-OWWL forecast, a number of research opportunities, as well as gaps in available knowledge or data have become evident. The following describe potential areas of future development and research that could improve our understanding and ability to predict coastal flooding hazard:

- The SWEEP-OWWL forecast can be used to simulate coastal flooding hazard during past storms, or hypothetical events that have not yet been observed. It is also straightforward to add climate change scenarios, such as sea-level rise or potential increases in wave height, and therefore investigate the effects of climate change on coastal flooding hazard into the future. Level one and two of the forecast (region and sub-region maps) can be used to quickly identify potential flooding hotspots now and in the future.

- Areas lacking in coastal profile data, such as north Devon could be included in the SWEEP-OWWL forecast by manually extracting coastal profiles from LiDAR data held by CCO. Although these data are not as accurate as CCO's measured topographic profiles, LiDAR are available at 1 m resolution around the entire southwest coastline.

- To facilitate a coastal flooding hazard forecast for the Isles of Scilly, a nested wave model domain and high resolution bathymetry data should be used to correctly resolve wave conditions in and around the islands.

- The measured coastal profiles used in SWEEP-OWWL will often not represent the beach elevations that occur during a storm, as significant beach changes may occur between the time of profile measurement and the time of a storm. Therefore, further work is being conducted to develop a probabilistic approach to predicting coastal flooding hazard, based on historic observations of each coastal profile. This would allow confidence bounds to be placed around each flooding forecast, and the prediction of worst-case and likely-case scenarios.

- Another potential option, especially for highly vulnerable sites, is the development of in-situ bed-level monitoring at sea defence structures. This would allow for more accurate and up to date prediction of the water depth (and therefore the maximum wave height) and freeboard in front of an engineered sea defence.

- New research is now being conducted at Plymouth University to investigate an empirical means with which to predict overtopping volumes, and therefore flooding hazard, at naturally defended beaches, which is not currently available in the literature. This could eventually replace the runup-based flood hazard thresholds currently implemented in SWEEP-OWWL.

- The empirical approach used in SWEEP-OWWL is highly computationally efficient. The prediction and plotting of coastal flooding hazard for all 186 profiles in the current database takes less than 20 minutes using a single computational core, once inshore wave conditions have been predicted (total modelling time is ~3 hours). As the SWEEP-OWWL system is modular, in future, the coastal flooding module could be fed by any high-resolution wave and water-level model such as the high powered computing cluster used by the Met Office, potentially enabling quicker or longer range forecasts.

6. Conclusions

- Predicting wave runup elevation and overtopping volume is essential in order to accurately forecast coastal flooding hazard in environments where wave conditions frequently exceed 1 m H_s, such as the southwest of the UK.

- It is also vital to correctly resolve wave conditions within embayments, otherwise flooding hazard can be over predicted in sheltered environments. Therefore the use of a fine resolution (e.g. 1 km) wave model grid to simulate nearshore waves is necessary along embayed coastlines.

- As current process-based models (for example XBeach) have not yet been developed and validated for the prediction of wave overtopping for all coastal profile types, and would be too computationally expensive to run for a region as large as the southwest, a suite of empirical equations that predict wave runup elevation and overtopping discharge were used in SWEEP-OWWL to efficiently forecast coastal flooding hazard.

- For engineered coastal profiles featuring a sea defence structure, the empirical equations in the EurOtop manual cover the most common overtopping scenarios. The relationship between overtopping discharge and coastal flooding hazard level is well understood through the research cited in the EurOtop manual, meaning that a hazard thresholding system, based on the predicted overtopping discharge, could be developed for SWEEP-OWWL in order to relate predicted overtopping to coastal flood hazard, on a scale of 1 (low hazard) – 4 (hazard to pedestrians, property, and vehicles).

- For natural coastal profiles that do not feature a sea-defence structure, and some scenarios where a sea-defence is present but fully emergent and above the still water level, wave overtopping hazard is poorly understood. To predict coastal flooding hazard for such cases, the Total Water Level (still water-level plus wave runup elevation) was compared to the elevation of the natural or engineered defences, and an objective thresholding was used to relate the relative elevation to the four hazard levels. Crude calibration of the thresholds was undertaken, but further research is required to better understand wave overtopping hazard in such cases.

- Coastal flooding hazard is controlled by wave and water-level conditions, but is also highly dependent on the elevation of the sea defences (natural or man-made), the sediment size and gradient of the coastal profile (for naturally defended profiles), and the water depth at the toe of man-made sea defences, which determines the maximum wave height that can reach the structure. Therefore, any coastal flooding forecast that seeks to predict wave overtopping requires detailed knowledge of each coastal profile. Fortunately, such data are now widely available around the UK through the coastal monitoring networks, such as the Channel Coastal Observatory, who typically monitor coastal profiles at least bi-annually.

- However, the measured topographic profiles used in SWEEP-OWWL often required supplementary information from LiDAR data and photographs. Furthermore, the profiles will often not represent the beach elevations that occur during a storm, as significant beach changes may occur between the time of profile measurement, and the time of the storm. To tackle this uncertainty, further work is being conducted to develop a probabilistic approach to predicting coastal flooding hazard, based on historic observations of each coastal profile.

- The empirical approach used in SWEEP-OWWL is highly computationally efficient. The prediction and plotting of coastal flooding hazard for all 186 profiles in the current database takes less than 20 minutes using a single computational core, once inshore wave conditions have been predicted. The 1 km wave and hydrodynamic model takes approximately 2.5 hours to complete a 4 day simulation (1 day hindcast plus 3 day forecast), using 8 cores and parallel computing.

- As the SWEEP-OWWL system is modular, the coastal flooding module could be fed by any high-resolution wave and water-level model such as the high powered computing cluster used by the Met Office. This means that the current total SWEEP-OWWL prediction time (approximately 3 hours) could be completed more quickly if the flooding module was coupled with a quicker wave and water-level model.

- Although the SWEEP-OWWL model was developed as an operational forecast, it can also be used for strategic purposes, for example to investigate the effects of climate change on coastal flooding hazard into the future. For example, the region and sub-region maps can be used to quickly identify potential flooding hotspots now and in the future.

References

Altomare, C., Suzuki, T., Chen, X., Verwaest, T. and Kortenhaus, A. 2016. Wave overtopping of sea dikes with very shallow foreshores. *Coastal Engineering*, **116**, 236-257.

Bruce, T., Pearson, J. and Allsop, W. 2004. Violent wave overtopping-extension of prediction method to broken waves. In: *Coastal Structures 2003.* pp 619-630.

Bruce, T., Van Der Meer, J., Pullen, T. and Allsop, W. 2010. Wave Overtopping at Vertical and Steep Structures. In: *Handbook of Coastal and Ocean Engineering.* World Scientific. pp 411-439.

EurOtop 2016. *Manual on wave overtopping of sea defences and related structures. An overtopping manual largely based on European research, but for worldwide application. Van der Meer, J.W., Allsop, N.W.H., Bruce, T., De Rouck, J., Kortenhaus, A., Pullen, T., Schüttrumpf, H., Troch, P. and Zanuttigh, B., www.overtopping-manual.com.*

Holman, R. A. and Sallenger, A. H. 1985. Setup and swash on a natural beach. *Journal of Geophysical Research: Oceans*, **90**, (C1), 945-953.

Masselink, G. and Hegge, B. 1995. Morphodynamics of meso- and macrotidal beaches: examples from central Queensland, Australia. *Marine Geology*, **129**, 1-23.

Poate, T., McCall, R. and Masselink, G. 2016. A new parameterisation for runup on gravel beaches. *Coastal Engineering*, **117**, 176-190.

Roelvink, D., Reniers, A., Van Dongeren, A., Van Thiel de Vries, J., Lescinski, J. and McCall, R. 2010. XBeach model description and manual. *Delft University of Technology, User Manual, Delft, The Netherlands*,

Stockdon, H. F., Holman, R. A., Howd, P. A. and Sallenger, A. H. 2006. Empirical parameterization of setup, swash, and runup. *Coastal Engineering*, **53**, 573-588.

van Rijn, L. C. 2014. A simple general expression for longshore transport of sand, gravel and shingle. *Coastal Engineering*, **90**, 23-39.

Appendix A. Example SWEEP-OWWL forecast PDF

OWWL Operational Wave & Water Level Model

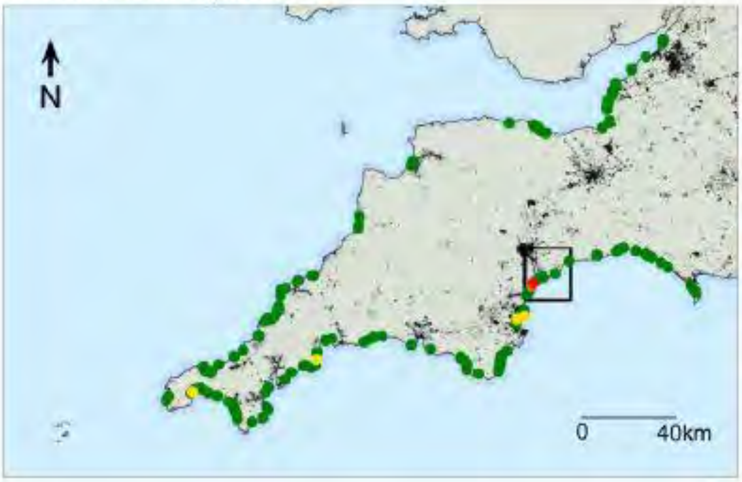
UNIVERSITY OF PLYMOUTH Marine Institute

Environment Agency

Coastal Flood Forecast

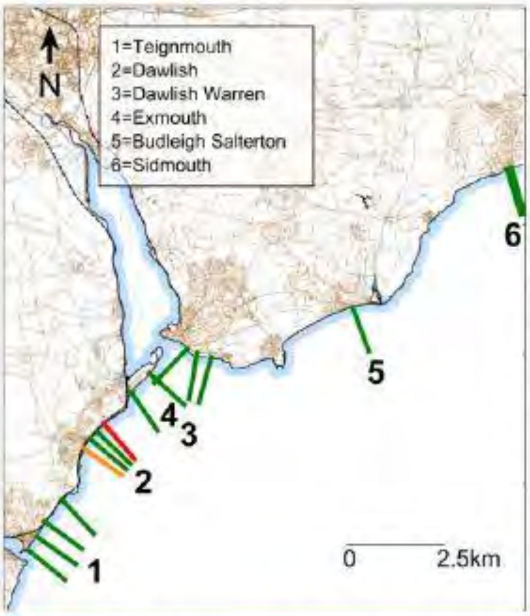
-Trial data, not for operational use-

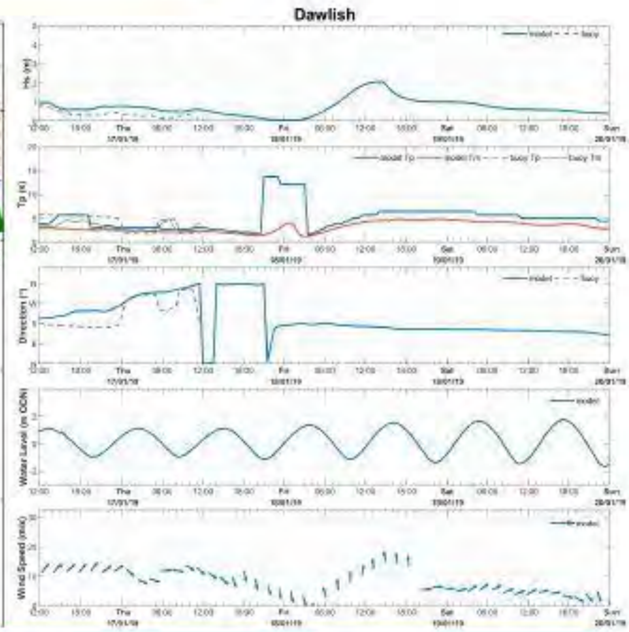
3-day forecast from 17-Jan-2019 12:00:00
Generated: 12:48 17 Jan 2019



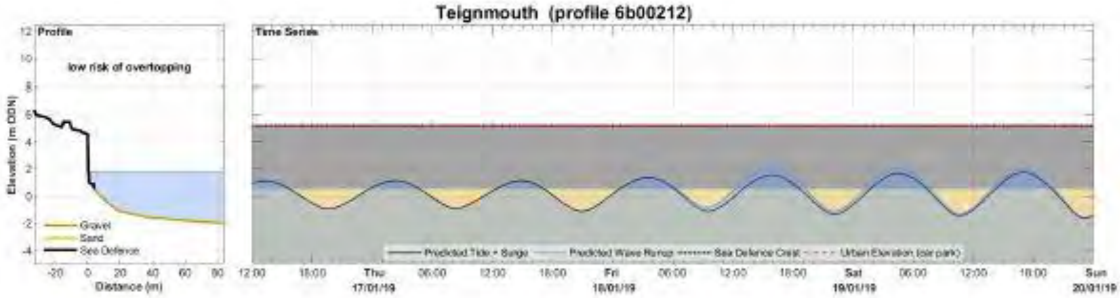
Coastal Flood Risk Level:

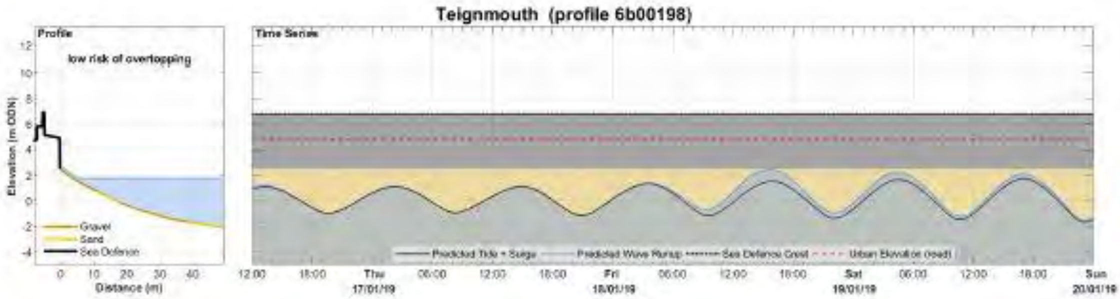
- Risk to Pedestrians/ Property/Vehicles
- Risk to pedestrians /property
- Risk to pedestrians
- Risk low

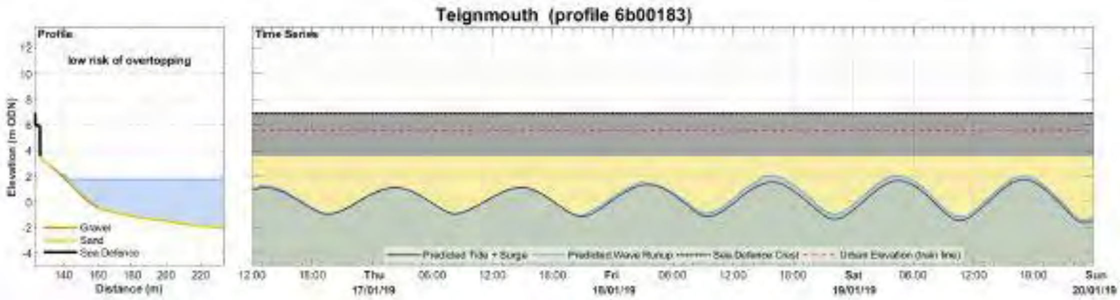


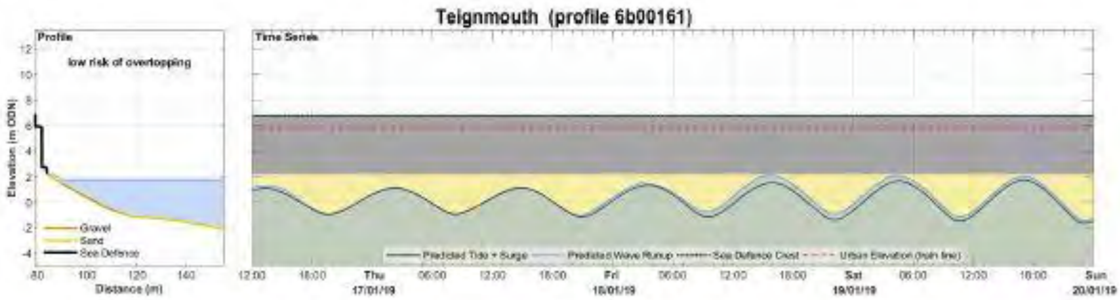


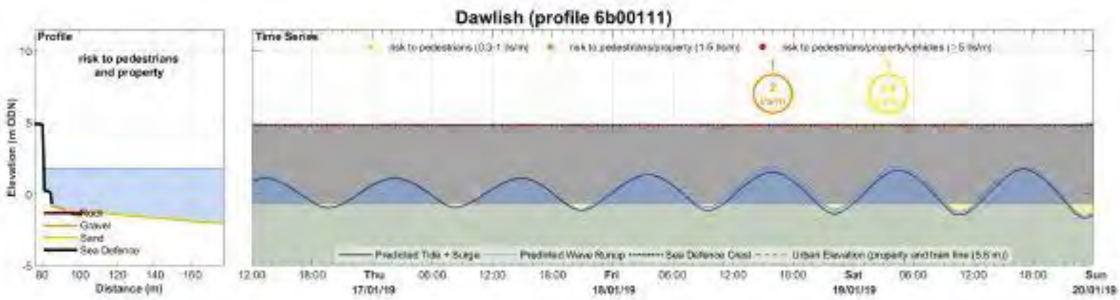
Boundary forcing data provided by the UK Met Office


Teignmouth (profile 6b00212)
low risk of overtopping


Teignmouth (profile 6b00198)
low risk of overtopping


Teignmouth (profile 6b00183)
low risk of overtopping


Teignmouth (profile 6b00161)
low risk of overtopping


Dawlish (profile 6b00111)
risk to pedestrians and property

Applying the natural capital approach to Sustainability Appraisal

© Tom Corser

© Andreas Trepte

FINAL REPORT
October 2020

Suggested citation

Hooper, T., and Austen, M. 2020. *Application of the natural capital approach to Sustainability Appraisal. Final Report*. October 2020. Report prepared as part of the South West Partnership for the Environment and Economic Prosperity (SWEEP) and the Marine Pioneer programme.

Contact

Tara Hooper
School of Biological and Marine Sciences
University of Plymouth
Drake Circus
Plymouth
Devon
PL4 8AA

Acknowledgements

This work was funded by the Natural Environment Research Council through the South West Partnership for the Environment and Economic Prosperity (SWEEP; grant NE/P011217/1). The authors are also very grateful to the North Devon Marine and Landscape Pioneer teams, Andrew Austen at North Devon Council, Alice Lord at Natural England, and to all the workshop participants.

Picture credits

Summary

The natural capital approach is based on recognising the contribution of nature to human welfare, and hence improving the manner in which the natural environment is traded-off against other things that are important to society. The natural capital system has three key components: the assets (species and habitats) and the ecosystem services (useful ecological products) that are provided by nature, and the goods and benefits that we receive from them, access to which requires human intervention through, for example, the availability of skills and infrastructure. There is significant policy momentum in the UK behind the adoption of the natural capital approach in natural resource management, but there remains no systematic or widespread application of the approach within impact assessment.

This report begins to outline the steps that could be taken to apply natural capital principles to Sustainability Appraisal (which was identified by stakeholders as the preferred mechanism for integrating the natural capital approach into local decision-making). As with any new methodology an iterative process is required, including significant engagement. This document represents an initial outline of the proposed methodology. It is expected to evolve, as lessons are learned from additional use of the framework in practice.

Incorporating the natural capital approach does not require a complete overhaul of Sustainability Appraisal. Instead, it offers an alternative means of framing sustainability issues that fits entirely within the existing process. The natural capital approach does not introduce environmental, social and economic factors beyond those that would be assessed for a standard Sustainability Appraisal; it simply suggests approaching the information and issues in a different way. Also, the approach does not require any additional data collection beyond that which would normally be undertaken; the expectation is that best available evidence will be used. The suggested method also seeks to fit to other obligations, processes and tools that may be relevant to planning and decision making at different scales.

The proposed framework is applicable initially during the scoping phase, as it sets up a protocol for gathering evidence and identifying sustainability issues, including using the wider five capitals model to break down overarching aims into their constituent parts from which specific objectives, indicators and targets can be derived that encompass the environment, infrastructure, individuals, and wider society. The method for collecting baseline information has four core elements: an asset register (in which information on the status of natural capital is compiled), an ecosystem services inventory (to list services, benefits and values); an asset-service matrix (to connect services to the assets from which they are derived); and a risk register (which summarises threats to continued system functioning).

Detailed habitat and ecosystem service classifications provide the framework for the collection/collation of baseline environmental information. This systematic approach also facilitates the construction of an evidence database, which supports data analysis, the subsequent evaluation of plan/programme impacts, and the monitoring of trends for subsequent updates and iterations. Holding evidence in a structured database also facilitates the creation of summary tables that present information clearly and coherently.

The process is designed to be comprehensive, but also flexible, recognising that Sustainability Appraisal is undertaken at different scales, in different contexts and with different levels of resource. Asset and service classifications are hierarchical, and so can be expanded or collapsed according to specific needs and scope. Summary tables are designed to be completed for the most part using three-point categorical rating scales, which recognises the likely difficulties in obtaining quantitative data for all elements of the evidence base. Even where complete quantitative data is available, summaries that can easily be given ‘traffic light’ coding are useful in highlighting key areas of concern and thus facilitate prioritisation.

The proposed scoping process provides a comprehensive and systematic baseline of the current status and trends in assets, services and benefits, and the degree to which they are at risk. This allows for the selection of detailed sustainability objectives and indicators that relate specifically to those assets and services, and for the full implications of plan options to be assessed, in turn supporting better outcomes than using high-level objectives and indicators such as the number and condition of protected sites.

The key steps in the method are outlined below, including the sections of the report in which they are described:

STEP 1 Set initial high-level sustainability objectives *[Section 3]*

With stakeholder input, and following identification and review of relevant programmes, policies and plans, define high-level objectives for each of the five capitals (natural, manufactured, human, social and financial)

Main output: A list of high-level objectives that define the scope of the Sustainability Appraisal

STEP 2 Collect baseline information [*Section 4*]

Step 2.1 Asset register

(a) Define assets of interest through a participatory stakeholder process, using the habitat classification hierarchy

(b) Select indicators for, and collect/collate data on, quantity, quality and spatial configuration of assets, including trends

Main output

Summary table of key asset data including 'traffic light' rating indicating where asset status and/or trend is of concern

Step 2.2 Ecosystem service inventory

(a) Define ecosystem services of interest through a participatory stakeholder process, using the ecosystem service hierarchy

(b) Select indicators for, and collect/collate data on, quantity and quality of ecosystem service, goods and benefits, including trends

(c) Determine ecosystem service delivery targets from local/national legislation, policy and management objectives

Main output

Summary table of key ecosystem service data including 'traffic light' rating indicating where ecosystem service status and/or trend is of concern

Step 2.3 Asset-service matrix

(a) Determine which assets are most important in the delivery of individual ecosystem services

Main output

Matrix with scores for the level of ecosystem service delivered by assets

STEP 3 Identify sustainability issues and problems using a risk register [*Section 5*]

(a) For each asset-service pair identified in the matrix, use the trend in asset status (determined from the asset register) and the target for ecosystem service delivery (defined by existing plans/policies) to assess the risk level.

(b) Amalgamate the individual scores into an overall risk category for each ecosystem service across all asset types.

Main output: Summary table using 'traffic light' coding to highlighting risks to continued delivery of services

STEP 4 Develop sustainability appraisal framework [*Section 6*]

(a) Use the outputs of the preceding steps to support a participatory process of defining detailed sustainability objectives that relate to specific natural capital assets and ecosystem services.

(b) Also use information gathered during the baseline assessment to identify indicators for assets and services that are appropriate in the local context and can be used to monitor progress against the sustainability objectives.

Main output: Table of sustainability objectives and their associated indicators

STEP 5 Evaluate effects of plan/programme alternatives on assets and services *[Section 7]*

(a) Using the same framework as for the previous steps, evaluate the likely level of impact of different plan/programme options on the different assets and ecosystem services to highlight key trade-offs.

(b) Use the outputs within a participatory process to identify the most appropriate options to be taken forward in the final plan/programme.

Main output: Summary table with 'traffic light' coding of impacts of plan/programme options on assets and services

Contents

1 Introduction

1.1 Background to the report

This report has been prepared as part of the South West Partnership for the Environment and Economic Prosperity (SWEEP)[1], a programme led by the Universities of Exeter and Plymouth and Plymouth Marine Laboratory together with partners in the public, private and third sectors, and funded by the Natural Environment Research Council. This work forms part of a wider project that is exploring ways to improve and extend the use of natural capital approaches in decision-making for the marine environment. The project was integrated within the North Devon Marine Pioneer, one of four Pioneers established by Defra through the 25 Year Environment Plan (HM Government, 2018), and led by the Marine Management Organisation. Outputs from the wider project include an analysis of the 'state of the art' in applying the natural capital approach in the marine context (Hooper et al., 2019a) as well as pilot natural capital asset and risk registers for North Devon and the Isles of Scilly (Ashley et al., 2018; 2020; Rees et al., 2019).

This report represents progress in developing a methodology for using the natural capital approach in Sustainability Appraisal, which is, to the authors' knowledge, the first time this has been attempted in either marine or terrestrial contexts. The development of a natural capital approach to Sustainability Appraisal, as with any new methodology, requires an iterative process including significant engagement. Sustainability Appraisal was identified at a stakeholder workshop in North Devon as the preferred mechanism for integrating the natural capital approach into local decision-making (Hooper, 2017). Specifically, this report presents an overarching conceptual framework and begins to outline the steps that could be taken in practice to apply natural capital principles to the Sustainability Appraisal process. A shorter method summary (Hooper and Austen, 2020) and supporting material has been prepared separately. While the approach was being developed, it became apparent that considering only the marine context was a limiting factor in the assessment, so the remit was expanded to also consider the terrestrial perspective, working in conjunction with Natural England and the Landscape Pioneer.

Case studies have been used to support development of the approach. The first relates to the South West Marine Plan, a case study that was undertaken at the request of the Marine Management Organisation (see Appendix 1). The Marine Plan was well advanced and so this work took account of the Sustainability Appraisal scoping already undertaken (MMO, 2016a,b,c; 2018) and drafts of other marine plan documents. The second case study concerned the North Devon Marine Natural Capital Plan, developed by the North Devon Biosphere Reserve as part of the Marine Pioneer and with funding from the European Marine Fisheries Fund (North Devon UNESCO Biosphere Reserve, 2020). This was the first such local marine plan attempted anywhere in the UK, and so provided a unique opportunity and an unconstrained application of the proposed process. The sustainability assessment prepared for the plan consultation is available as a separate report (reproduced in Appendix 2). The methodology was further refined through consideration the North Devon and Torridge Local Plan (Torridge District Council and North Devon Council, 2018) as well as wider developments nationally and in the Marine and Landscape Pioneer programmes. It is expected that the approach will continue to evolve with additional testing.

1.2 Sustainability Appraisal

The planning framework in England, both terrestrial and marine, seeks to promote sustainable development and to minimise and mitigate environmental impacts (Ministry of Housing, Communities and Local Government, 2018; HM Government, 2011a). There is a statutory obligation for responsible authorities at local, regional and national level within England to evaluate the environmental effects of plans and programmes, including those within England's territorial waters, under Statutory Instrument 2004 No. 1633: The Environmental Assessment of Plans and Programmes Regulations 2004. Such impact assessment is also mandated in the context of the European Union Directive 2001/42/EC, which details the requirements for Strategic Environmental Assessment (SEA) of plans and programmes.

[1] https://sweep.ac.uk/

In parallel with environmental criteria, development strategies also need to consider economic and social objectives and impacts. Sustainability Appraisal is a key mechanism for holistic assessment of environmental, economic and social implications of plans and programmes, and is designed to fulfil simultaneously the requirements of UK legislation and the SEA Directive (MHCLG, 2019a; HM Government, 2011a; ODPM, 2004). Its application is again enshrined in legislation. The Planning and Compulsory Purchase Act 2004 requires that regional planning bodies and local planning authorities carry out Sustainability Appraisal during the development of regional spatial strategies and local development plans. Sustainability Appraisal is also explicitly required for marine plan proposals under the Marine and Coastal Access Act 2009.

Although the circumstances in which Sustainability Appraisal is necessary are clearly mandated, the exact form such an appraisal should take is not. The overarching process of Sustainability Appraisal is well established, with clearly defined steps that follow the broad scheme outlined in Figure 1 (ODPM, 2004; MHCLG, 2019b; MMO, 2016a). The steps are modified depending on the scale of the plan (Neighbourhood Plans have a slightly different process from Local Plans, for example) and ongoing engagement and consultation is expected throughout. Additional broad guidance has been produced by many agencies including government departments and statutory authorities (e.g. ODPM, 2004; MHCLG, 2019b; MMO, 2016a; Historic England, 2016; MOD, 2018; RTPI, 2018).

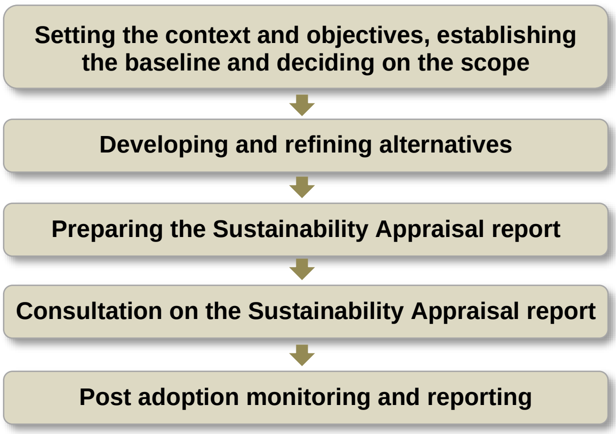


Figure 1. The broad steps in the Sustainability Appraisal process (adapted from MHCLG, 2019b).

The exact nature of the environmental, social and economic information that should be collected, and how it should be presented, is not prescribed, and it would be impractical to attempt to do so given the varied contexts in which Sustainability Appraisal could be applied. Annex I of the SEA Directive (replicated in Schedule 2 of the Environmental Assessment of Plans and Programmes Regulations 2004) requires that assessment is made of "*the likely significant effects on the environment*" and the interrelationships between its individual components. The Annex further provides high level examples of these different environmental components, which encompass ecological, social and economic factors (further details are provided in Section 2). In the marine context, the Marine Policy Statement (HM Government, 2011a) requires consideration of a similar broad list of environmental issues as well as key activities (such as marine protected areas, fisheries, and energy). Within these broad frameworks, however, there are opportunities to explore different ways to collect, assess and report the necessary information on the environmental, social and economic implications of plans and programmes.

1.3 The Natural Capital Approach

One option for a different approach is to use a natural capital framework to underpin the Sustainability Appraisal process. The natural capital approach is described by Hooper et al. (2019a, p2) in a report commissioned by Defra to explore its application to the marine environment:

"The natural capital approach is a somewhat broad term that encompasses assessment of the quantity, quality, function and value of environmental assets and the goods and services that flow from them, with the aim of ensuring the sustainable use of natural resources. Fundamentally, the approach is based on recognising the contribution of nature to human welfare, and hence improving the manner in which the natural environment is traded-off against other things that are important to society. The concept of value is central to the natural capital approach, as it seeks to better integrate environmental and economic information and thus to redress the historic trend in which natural capital and ecosystem services were undervalued and overexploited. Equally important is documenting ecological status as the characteristics of assets are usually only partially reflected in monetary values."

The natural capital system has three key components: the assets (species and habitats) and the ecosystem services (useful ecological products) that are provided by nature, and the goods and benefits that we receive from them, access to which requires human intervention through, for example, the availability of skills and infrastructure (Hooper et al., 2019a; Figure 2). Valuation is a central theme of the natural capital approach, and monetary value is an important metric for the measurement of goods and benefits. However, the status of assets, functions, and processes is determined through condition assessment using ecological metrics. Ecosystem services are also usually defined in ecological terms, although value-based metrics may be appropriate. (Hooper et al., 2019a; Figure 3).

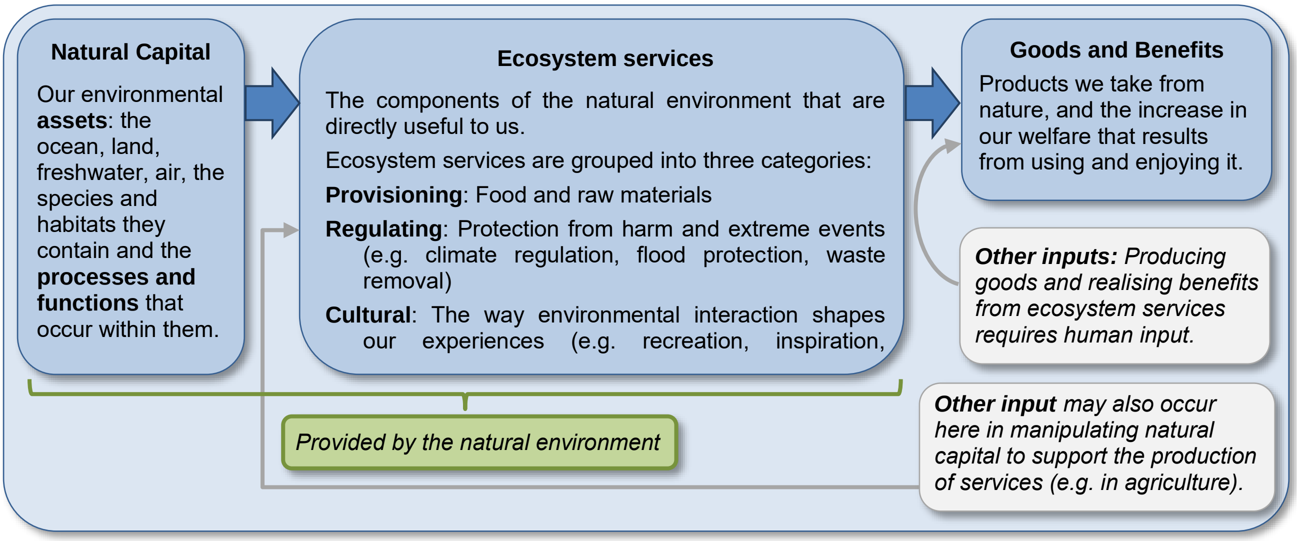


Figure 2. They key elements of the natural capital system (adapted from Hooper et al., 2019b)

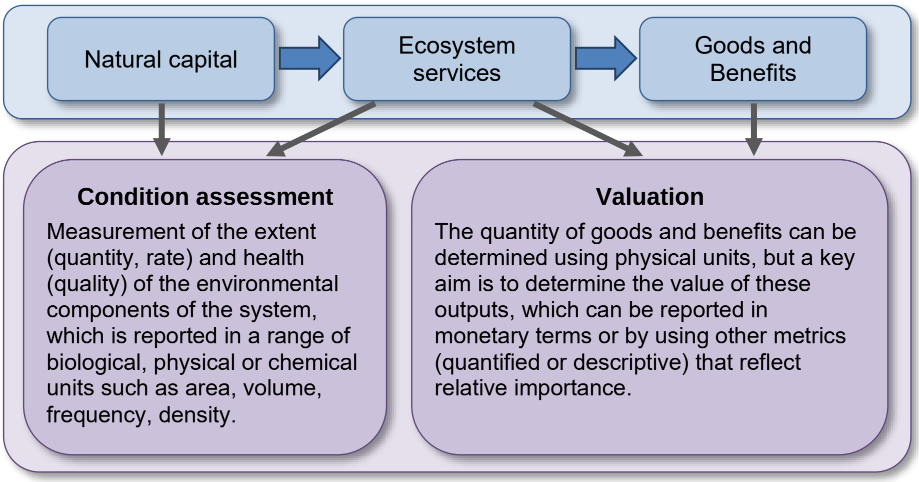


Figure 3. Measurement of the different components of the natural capital system (Hooper et al., 2019b)

The total value of the environment is comprised of many elements, including the non-use values which are derived just from knowing a species or habitat exists (the existence value) and that resources will still be available for future generations (bequest value). The benefits derived from actually using ecosystems can be further divided according to whether the benefit is obtained from direct or indirect use, or from some as yet unknown future use (the option value) (Figure 4). Monetary values are most easily derived where there are markets (e.g. fish landings or crop harvests), but methods exist to provide a monetary metric for other values. In practice, monetary valuation is difficult for many ecosystem services, and decision-makers often need to use other metrics for value, including through describing it in qualitative terms. Values can also fluctuate for reasons that are not linked to the state of the underlying asset (as a result of wider market trends for example).Therefore, decision-makers need to maintain a focus on the health of assets in order to ensure a sustainable flow of services and benefits.

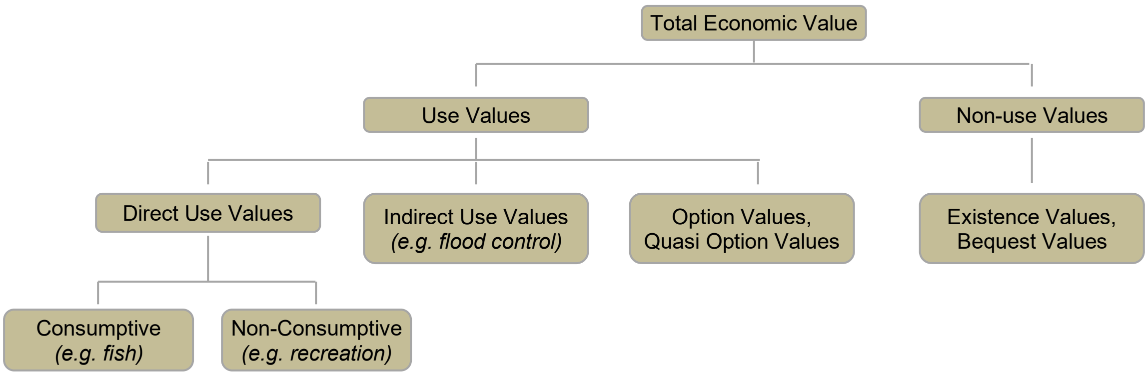


Figure 4. The different components of economic value (from Barbier, 1994; Turpie, 2003.)

Considerable literature exists that provides more detail on the natural capital approach, ecosystem services and valuation. In addition to extensive academic literature, this includes the outcomes of national and international programmes such as:

- The Millennium Ecosystem Assessment (2003)
- The Economics of Ecosystems and Biodiversity (TEEB, 2010);
- UK National Ecosystem Assessment (2011, 2014);
- EU Working Group on Mapping and Assessment of Ecosystems and their Services (MAES; Maes et al., 2013, 2018; Erhard et al., 2016);
- Natural Capital Committee (2013, 2014, 2015, 2017, 2019a,b);
- Common International Classification of Ecosystem Services (CICES; Haines-Young and Potschin 2013, 2018)
- Enabling a Natural Capital Approach (ENCA; Defra, 2020).

The recent Defra report (Hooper et al., 2019a) provides a detailed review of the natural capital approach, with a focus on UK policy and the marine context. There is a further wide literature on economic valuation including introductory guides produced by, or on behalf of, the UK Government (e.g. Defra, 2007; eftec & Environmental Futures Ltd., 2006).

1.4 The benefits of integrating the two approaches

There is significant policy momentum in the UK (and particularly England) behind the adoption of the natural capital approach in natural resource management. The UK National Ecosystem Assessment (2011, 2014), which was part-funded by the UK Government and devolved administrations, represented the first national-scale assessment anywhere in the world of the benefits provided by nature to society and the economy. This coincided with an Environment White Paper (HM Government, 2011b) that established natural capital thinking as a key component of UK environmental policy through commitments to develop natural capital accounts and to establish a Natural Capital Committee to advise government. This has been taken further in the 25 Year Environment Plan (HM Government, 2018), which explicitly states that "*over the coming years the UK intends to use a 'natural capital' approach as a tool to help us make key choices and long-term decisions*."

Natural capital ideas and language are also becoming more widespread beyond the direct remit of Defra. The Green Book (HM Treasury, 2018), for example, provides comprehensive, approved guidance, methods and tools for appraisal process related "*to all proposals that concern public spending, taxation, changes to regulations, and changes to the use of existing public assets and resources.*" The most recent edition explains that the natural capital framework "*by providing a more comprehensive framework within which to develop and appraise policy, it suggests additional options to meet policy goals and enables all options to be assessed more accurately for potential improvements and/or damage to the environment.*" The Green Book further provides guidance on approaches to monetary and non-monetary valuation of natural capital. Within planning, the National Planning Policy Framework (MHCLG, 2019a) emphasises that planning policies and decisions should recognise "*the wider benefits from natural capital and ecosystem services*" and "*plan for the enhancement of natural capital*".

This policy position reflects well-established calls to reframe arguments for the conservation of nature (and hence natural resource management) in ways that better link the environment, society and the economy. It has long been argued that "*sustainable development is based on constant or augmented natural capital stock*" and that conserving or improving the natural capital stock directly contributes to the "*social objectives of equity within and between generations, economic efficiency and resilience*" (Pearce, 1988). Fundamentally, proponents of a natural capital approach believe that what we know about the natural environment is not being effectively synthesized and communicated to decision makers and the public, and so they are poorly equipped to make environmental trade-offs (Daily, 1997). The natural capital approach is intended to provide an alternative perspective and set of tools that can improve understanding of the value of the environment, our dependence on it, and the wider implications of allowing it to decline.

The academic literature further outlines the specific potential for applying a natural capital approach to impact assessment. This is considered primarily in the context of ecosystem services, which have been the focus of a larger body of research than the wider natural capital approach. The approach is considered appropriate for both SEA and also Environmental Impact Assessment (EIA) (e.g. Geneletti, 2016; Karjalainen et al., 2013; Rozas-Vásquez et al., 2017). Ecosystem service approaches are considered particularly appropriate for impact assessment, because the interaction between the environment, society and the economy is inherent in both processes (Geneletti et al., 2015) and there is already implicit consideration of ecosystem services within current practice (Honrado et al., 2013).

The language of natural capital is also becoming more prevalent beyond the academic literature. Brief reference to ecosystem services is made within the SEA for offshore energy in the UK (DECC, 2016) and, at the local authority level, aspirations to embed ecosystem services principles are clear within the North Devon and Torridge Local Plan (Torridge District Council and North Devon Council, 2018). In marine planning, extensive reference is made to natural capital assets and ecosystem services within the 'Iteration 3' environment consultation documents for the draft marine plans (MMO, 2019a), including around the need to minimise and mitigate adverse effects on marine or coastal natural capital assets and to enhance these assets where possible. Realising such aspirations requires proper classification, characterisation and assessment of all elements of the natural capital system at all stages of the development, implementation and evaluation of plans and policies, including in Sustainability Appraisal.

The natural capital approach also has the potential to bring some practical benefits in terms of streamlining the way in which information in impact assessment is summarised and reported. Asset and risk registers are proposed, respectively, as inventories of the present extent and condition of natural capital assets, and the current and future risks to them (Natural Capital Committee, 2017). This information is a fundamental starting point for impact assessment, and compiling it in the format of asset and risk registers provides a systematic means of summarising the large volumes of text typically included in impact assessment reports. The recent 'report card' format in which outcomes of the

Sustainability Appraisal scoping for marine plans were documented (MMO, 2016b) illustrates the benefits of improved summary formats.

Practical guidance (albeit high level) on how to incorporate ecosystem services into impact assessment is also beginning to emerge, including through the UK National Ecosystem Assessment (Scott et al., 2014), from the Scottish Government (2016) and, beyond the UK, by the World Resource Institute (2013). The EIA industry is also beginning to adopt the language of natural capital (CIEEM, 2016) although has not yet provided methodological detail for practitioners. There is also an example of an application of ecosystem services within a 'real world' Sustainability Appraisal. The Sustainability Appraisal for the Marine Plan for Northern Ireland (AECOM & ABPmer, 2018) contains a high-level qualitative assessment (based on expert judgment) of changes in ecosystem services associated with the implementation of the Marine Plan compared to the baseline of no plan. This is provided in addition to the more usual 'topic-based' approach (discussed further in Section 2). However, there remains no systematic or widespread application of ecosystem services within impact assessment at the programme, plan or project level, and there appear to have been no attempts as yet to utilise the wider natural capital approach.

2 Conceptual framework for the proposed approach

2.1 Framework diagrams and descriptions

Sustainability Appraisal requires a comprehensive assessment of many different aspects of the ecosystem and its interactions with society and the economy. Annex I of the SEA Directive (and Schedule 2 of the Environmental Assessment of Plans and Programmes Regulations 2004) lists "*biodiversity, population, human health, fauna, flora, soil, water, air, climatic factors, material assets, cultural heritage including architectural and archaeological heritage, landscape*" as examples of the environmental factors which must be considered in assessment of the effects of plans and programmes. Categorisation of the environmental components of Sustainability Appraisal often tends to take a 'topic-based' approach of adhering closely to these subjects as listed (e.g. AECOM and ABPmer, 2018; Lepus Consulting. 2019). While this provides a functioning process through which to undertake the required assessment, it perhaps does not present the information obtained in a way that best facilitates whole system understanding or highlights key trade-offs. The natural capital approach provides an alternative way to frame the gathering and presentation of the information required under planning regulations.

The natural capital approach is intended to increase emphasis within decision-making on the natural environment, what it provides for people, and the value of this. However, decision-making bodies such as Local Authorities have wide-ranging responsibilities (including for social services, crime and education for example) some of which may have only minimal, or even indiscernible, direct relationships to the natural environment. Therefore, if the natural capital approach is to be integrated into Sustainability Appraisal in an efficient and effective manner, an overarching framework is required that captures all the elements likely to be pertinent to this wider decision-making context. The Five Capitals model (Forum for the Future, undated; (Figure 5) is already widely used in sustainable development contexts, including in local planning (such as by Powys County Council (2017) in their Local Development Plan) and thus provides a suitable framework for Sustainability Appraisal in which to nest an more comprehensive approach to natural capital assessment. The model further reinforces the importance of the natural environment, on which, ultimately, the production of all other capitals relies. The interconnected environmental, social and economic system can be represented using natural capital terminology in an overarching conceptual diagram (Figure 6).

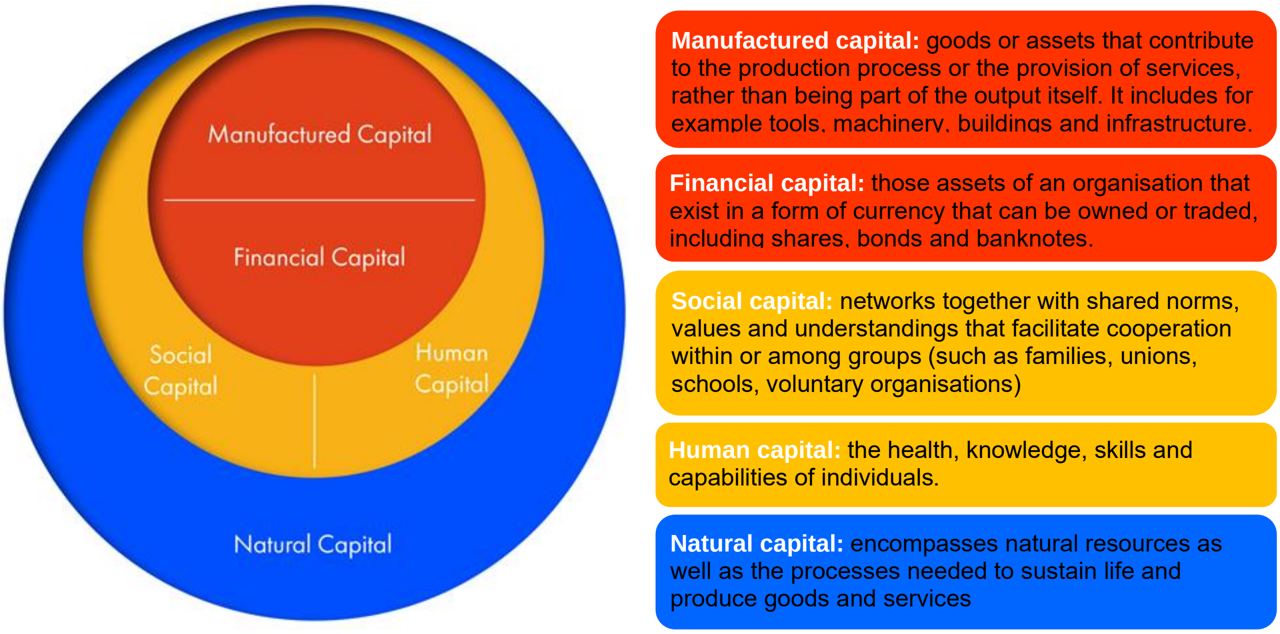


Figure 5. The Five Capitals Model (Forum for the Future, undated) with associated definitions of each type of capital (Forum for the Future, undated; Hattam et al., 2017)

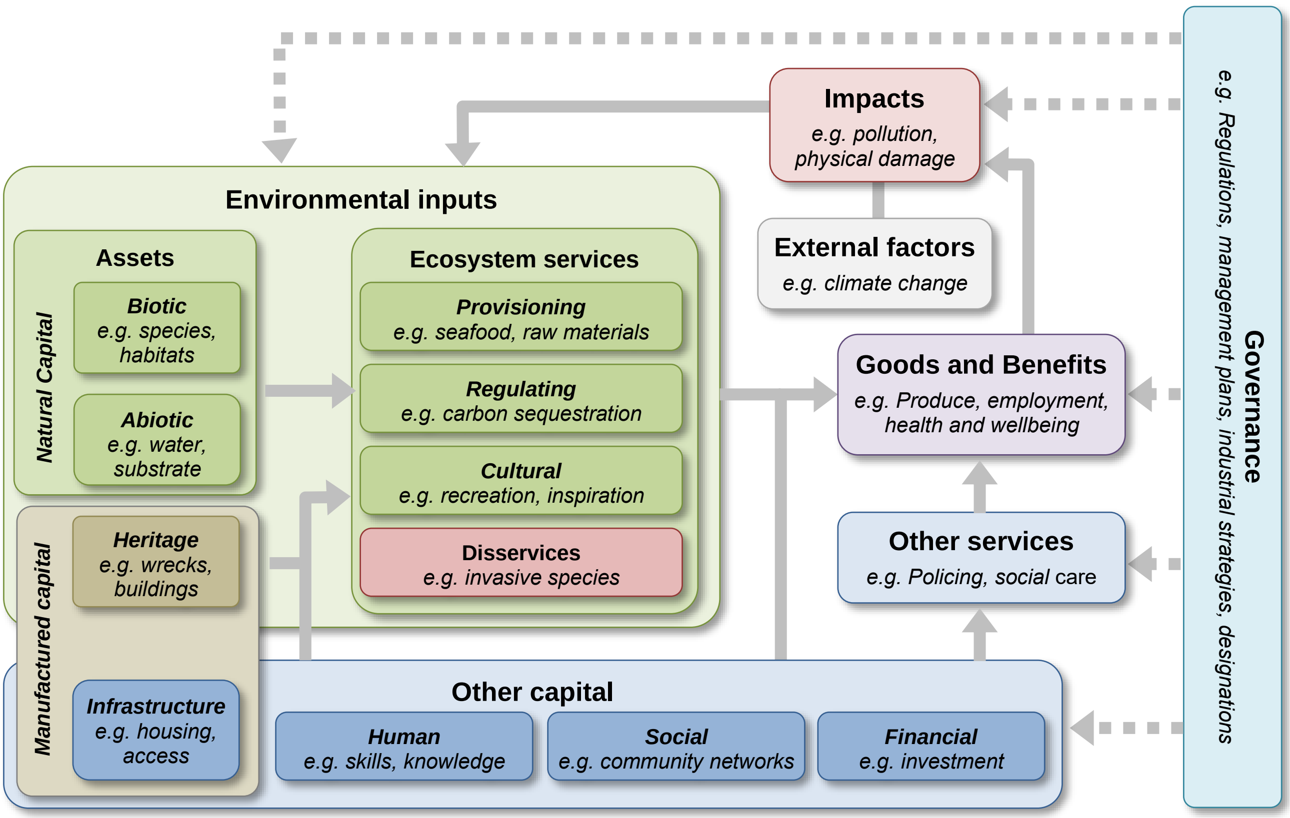


Figure 6. The overarching conceptual framework for the approach, showing how the elements considered in a Sustainability Appraisal interact with natural capital

The ecosystem provides **natural capital assets**: species, habitats, and abiotic components such as water and substrates. As pointed out by Firth (2019), the fundamental role of people in shaping the environment, and hence the connection between natural capital and heritage, is typically neglected in existing natural capital frameworks. To address this, the framework adopts a broad definition of **environmental inputs**, within which the heritage assets of **manufactured capital** (such as buildings and shipwrecks) are included. The explicit inclusion of heritage as an environmental input is in keeping with the SEA topics and with Sustainability Appraisal in practice, where listed buildings and other aspects of heritage are often grouped within overarching environmental quality objectives (e.g. Torridge District Council and North Devon Council, 2018). Heritage assets are also often managed in same way as natural capital assets, through designations and protected status.

These assets generate **ecosystem services** including harvestable stocks of seafood and raw materials (provisioning services), carbon storage and mitigation of flood risks (regulating services), and opportunities for leisure and recreation (cultural services). The term 'ecosystem services' is maintained for convention, even though some services should be termed 'environmental' as they relate to abiotic or heritage factors, rather than being produced by living organisms. Not all ecosystem services are positive, however. Natural ecological phenomena such as the proliferation of invasive species and algal blooms can have negative consequences for society or economic activity. These are termed **disservices**.

Other capital inputs including manufactured infrastructure, the skills of individuals, social networks, and financial investment, can be applied during the production of ecosystem services. This typically occurs within agriculture and aquaculture, for example the application of fertiliser or the deployment of settlement surfaces for shellfish. Other capital inputs are essential in the conversion of ecosystem services into useful **goods and benefits** that have a market value or contribute to our health and wellbeing. Fish stocks, for example, cannot be exploited without fishing vessels, equipment, and the expertise and knowledge of fishermen. The framework also includes **other services** (such as addressing crime, and providing social care), which do not have a direct relationship to environmental inputs but are important components of, for example, local plans which need to consider extensive social and economic issues.

The process of obtaining goods and benefits from the environment can have negative **impacts** upon it, both on the natural capital asset being exploited (such as through overfishing, or recreational disturbance caused by wildlife watching vessels) and the wider ecosystem (through, for example, abrasion, entanglement or collision). Maritime activities may also have positive benefits for natural capital and ecosystem services, such as shellfish aquaculture increasing water quality or the artificial reef effects of offshore wind farms providing nursery areas for commercial fish.

Many elements of the system are subject to **governance**, whether this is through the designation of protected areas, regulations to minimise and mitigate the impacts of certain activities, or management plans and industrial strategies that document objectives and priorities for key issues such as flood risk mitigation and economic development. The environment underpinning, and affected by, any particular plan, programme or project is not a closed system, particularly in the marine context with the interconnections provided by the water column. **External factors** beyond the geographical boundaries of a particular plan or programme and/or the jurisdiction of those responsible for its implementation also effect change on natural capital. Climate change is a key external factor, with other examples including pollution from airborne particulate matter, upstream discharges, and global ocean currents.

2.2 Fulfilling statutory criteria

It is essential that any new framework for Sustainability Appraisal complies with the requirements of the relevant legislation. A detailed assessment of the baseline information contained withing a standard Sustainability Appraisal was used to examine the suitability of the proposed framework, and is discussed in more detail in the marine planning case study (Appendix 1). As shown in Table 1, there are multiple ways to map the environmental factors listed in the SEA Annex I onto the proposed natural capital elements, and thus the framework will allow comprehensive consideration of all of these factors, and their interactions, as required by planning legislation.

Table 1 does not include two topics from the SEA Directive Annex 1. ‘Material assets’ are not an element of natural capital, but fit within the wider framework as manufactured capital (e.g. roads, buildings, other infrastructure). Similarly, ‘Population’ tends to be interpreted as relating to demographic factors such as population size and density, employment structure, and deprivation, which again are not natural capital components. However, goods and benefits derived from the environment (which support jobs and therefore interact with demographics) are described for each element of the natural capital system. This illustrates a key benefit of the natural capital approach over the standard ‘topic-based’ framing of sustainability issues: the natural capital framework makes explicit how these factors (from assets to employment) are connected. Other elements of the conceptual framework feature in the Sustainability Appraisal process in other ways: for example, governance is considered by the identification of other relevant policies, plans and programmes that occurs during the first step of a Sustainability Appraisal, and impacts are evaluated within the stage of developing and refining alternatives.

Table 1. The key elements of the natural capital system, with indicative (but not exhaustive) examples of the multiple ways these map onto the environmental topics as listed in Annex 1 of the SEA Directive

SEA Directive Annex 1 Topic	**Environmental Inputs**		**Goods/Benefits**
	Assets	***Ecosystem Service***	
***Biodiversity, Fauna, Flora**	Species populations and habitats	Pollination and seed dispersal; cultivated and wild food stocks; non-food products	Quantity/value of crop and fish harvests and wildlife watching trips; wellbeing related to existence of wildlife
Soil	Soil types, species populations and habitats	Weathering, decomposition and fixing processes and their effect on soil health	Quantity/value of crop harvests
Water	Water bodies	Water supply, hydro, tidal and wave energy potential, transport options	Water for drinking and irrigation, electricity, shipping, recreation and leisure
Air	Wind conditions, species populations and habitats	Dilution by the atmosphere, bioremediation and filtration, wind energy potential	Clean air, electricity
Climatic factors	Species populations and habitats, water bodies, geological features	Regulation of temperature, humidity and chemical composition of the atmosphere and oceans, flood and erosion control	Stable climate, mitigation of impacts from climate change
Cultural heritage	Wrecks, listed buildings, monuments and their settings; Iconic species; Ancient woodlands	Characteristics of living systems that are resonant in terms of culture or heritage and/or have symbolic, sacred or religious meaning	Recreation, leisure, inspiration, wellbeing
Landscape	Habitats, as well as water bodies and geological features	Characteristics of living systems that enable observational interactions and aesthetic experiences	Recreation, leisure, inspiration, wellbeing
***Human health**	Species populations and habitats, water bodies	Disease and pest control; noise reduction; visual screening; flood control, observational and immersive interactions, aesthetic experiences	Improved health/wellbeing from food, clean air and water, flood protection, interactions with nature

* NOTE: Biodiversity, flora and fauna supports all assets and ecosystem services except those provided by non-living components of the ecosystem, and human health/wellbeing is a key benefit of most ecosystem services so these categories also interact with the other SEA topics.

2.3 Scope of the proposed methodology

Sustainability Appraisal is well-established and follows an accepted process (as described in e.g. ODPM, 2004). Incorporating the natural capital approach does not require that process to be completely overhauled. Instead, it offers an alternative means of framing sustainability issues that fits entirely within the stages and steps of the process as already defined. The natural capital approach does not introduce environmental, social and economic factors beyond those that would be assessed for a standard Sustainability Appraisal; it simply suggests approaching the information and issues in a different way. Also, the approach does not require any additional data collection beyond that which would normally be undertaken; the expectation is that best available evidence will be used.

The proposed framework is applicable initially during the scoping phase, as it sets up a protocol for gathering evidence and identifying sustainability issues. This is done through the four core elements: an asset register (in which information on the status of natural capital is compiled), an ecosystem services inventory (to list services, benefits and values); an asset-service matrix (to connect services to the assets from which they are derived); and a risk register (which summarises threats to continued system functioning). These are described in detail in Section 4.

The natural capital approach also applies to the second stage in Sustainability Appraisal, that of developing and refining alternatives. Again, using the proposed approach does not change the overarching requirements for this phase, but recommends assessing the implications of plan/programme options against the framework established for the scoping phase. Steps such as consultation, developing alternative options, and proposing monitoring strategies do not require alternative methods, but can be applied to the information as organised under the natural capital framework. The steps in the Sustainability Appraisal process for which a natural capital methodology is proposed, and hence the scope of this guidance, are outlined in Figure 7.

The proposed process is comprehensive, with a detailed and systematic approach to collecting baseline information and identifying sustainability issues. It is important to ensure that the scoping phase provides a sufficient understanding of what natural capital assets are present, what ecosystem services are supplied, and the goods and benefits that result. Documenting the extent and status of individual assets allows for the selection of detailed sustainability objectives and indicators that relate specifically to those assets, and for the full implications of plan options to be assessed. This in turn supports better outcomes than using high-level objectives and indicators such as the number and condition of protected sites.

The proposed natural capital framework is designed to be comprehensive while also recognising that Sustainability Appraisal is undertaken at different scales, in different contexts and with different levels of resource. Therefore, it is flexible and can accommodate differences in the requirements for (and availability of) data. The framework has been developed with the broader planning and licensing system in mind, and so has a wider application beyond Sustainability Appraisal. For example, the framework can be used at more strategic levels such as in setting overarching Local Plan objectives, not just those for the Sustainability Appraisal. Furthermore, the proposed framework can also be applied to Environmental Impact Assessment, and so supports better integration of assessment at site and strategic scales.

In order facilitate use of the framework in a range of contexts, the approach seeks to fit to other obligations, processes and tools that may be relevant to planning and decision making at different scales. This includes in particular the Biodiversity 2.0 metric for assessing net gain (Crosher et al., 2019), but also to the work undertaken by Natural England in developing natural capital indicators and atlases (Lusardi et al., 2019; Wigley et al., 2020) and Defra's guidance on Enabling a Natural Capital Approach (ENCA; Defra 2020). ENCA relates particularly to accounts and valuation, which are not a primary focus of Sustainability Appraisal. However, consideration of ENCA in designing the Sustainability Appraisal framework should allow for greater coherence if agencies (such as Local Authorities) also seek to develop natural capital accounts. The common conceptual elements between Sustainability Appraisal and ENCA are shown in Figure 8.

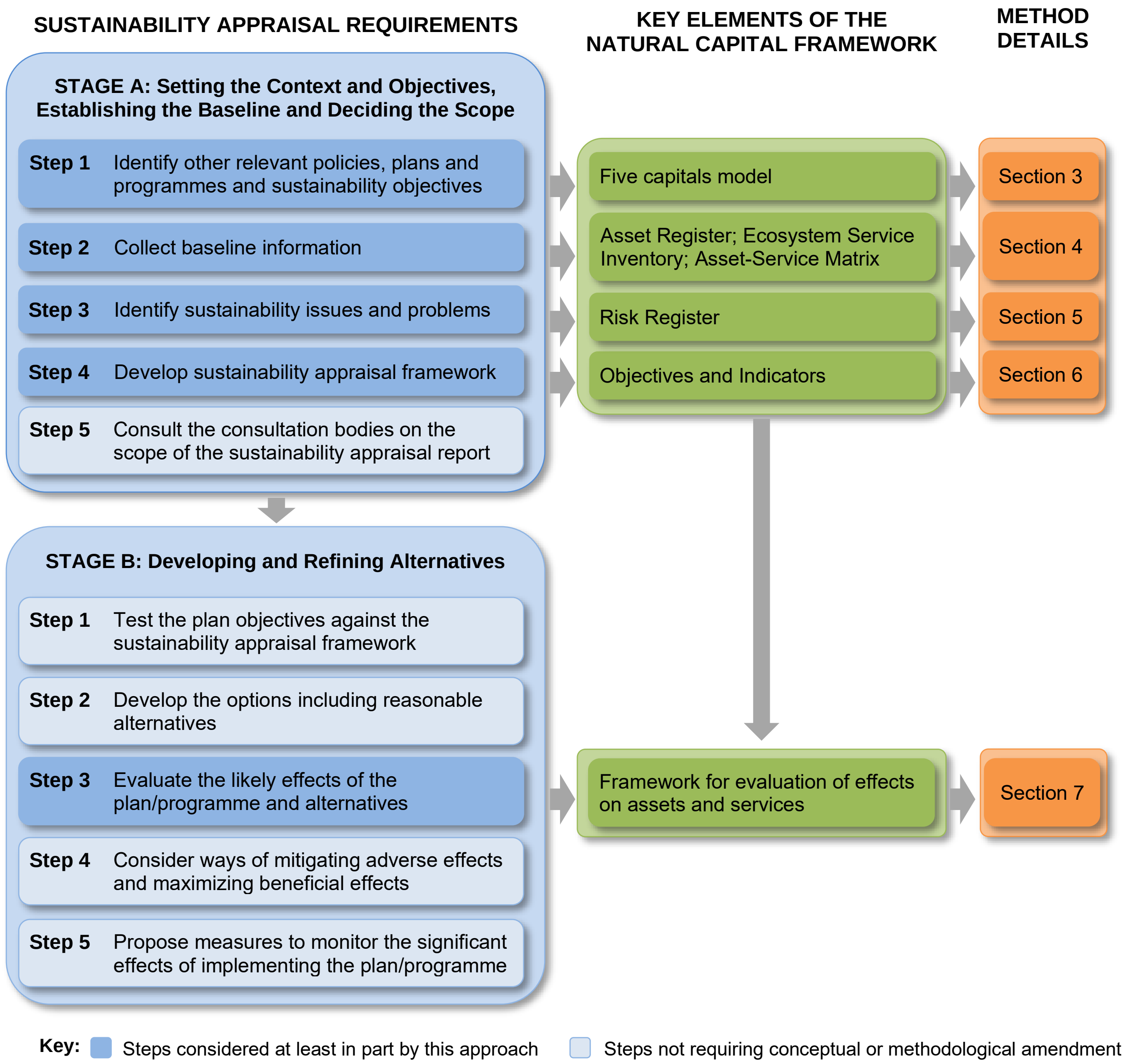


Figure 7. The steps in Sustainability Appraisal (based on MHCLG, 2019b) for which a natural capital methodology is proposed, the key elements of the framework relating to each, and the relevant sections in this report.

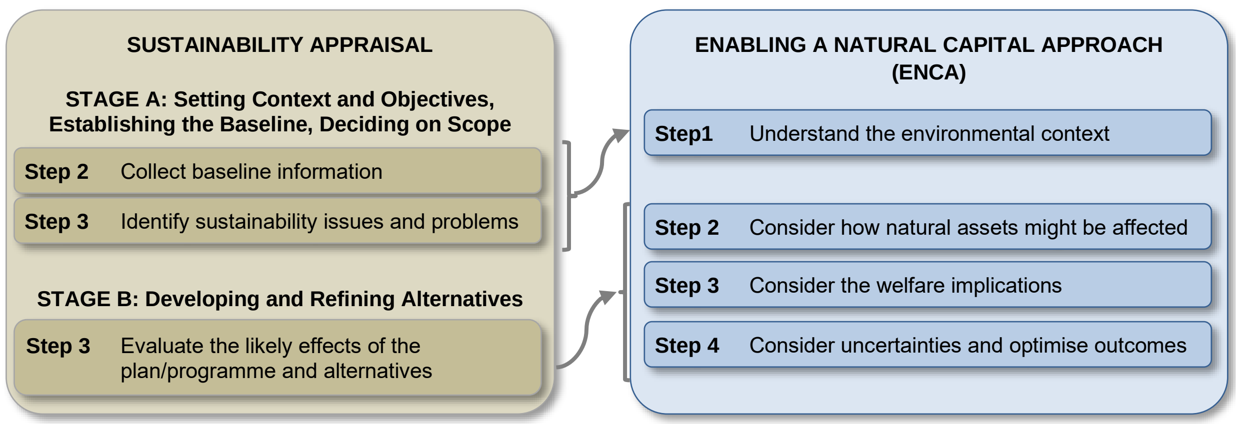


Figure 8. The common conceptual elements between Sustainability Appraisal and Defra's Enabling a Natural Capital Approach (ENCA; based on MHCLG, 2019b and Defra, 2020).

2.4 Building a natural capital database

In addition to any narrative reporting, a comprehensive database should be constructed that allows for information to be systematically recorded (supporting subsequent analysis) and from which summary sheets can be drawn in order to present information clearly and coherently. While such databases may not be a common component of reporting they are not unheard of. A substantial database was used to compile evidence during scoping for the Sustainability Appraisal for UK Marine Plans (MMO, 2016c). As will be described in detail in the sections that follow, the proposed database will contain information on the quantity, quality, trends, designations and other management of assets together with details of ecosystem services provided, the goods/benefits they supply and who benefits; a matrix to connect assets and services; and a summary of risks to the continued delivery of benefits. This will serve to demonstrate the breadth and extent of support the local environment provides to people within and beyond the plan/programme area.

The content of summary tables is outlined within this guidance. They are designed to be completed for the most part using three-point categorical rating scales (high, medium, low; increasing, stable, declining; etc). This recognises the likely difficulties in obtaining quantitative data for all elements of the evidence base, particularly for marine areas (and hence the need to use expert judgement). Also, even where complete quantitative data is available, summaries that can easily be given 'traffic light' coding are useful in highlighting key areas of concern and thus facilitate prioritisation. The process of determining the rating, the underlying information used, and assumptions made should be included as part of the wider evidence base. The evidence base should further include confidence assessments, to highlight possible inadequacies in the available data, and list sources of data and other references used. Such information should not be limited to published documents, and details of any sources such as personal communications, stakeholder workshops or expert judgement should also be given. Approaches for confidence assessments are not included (they are not specific to natural capital); reference should be made to general best practice. Geographical Information Systems (GIS) should be used where possible, as mapped outputs aid visualisation and interpretation, and support spatial planning. Again, GIS techniques are not specific to natural capital and so are not described here.

Detailed habitat and ecosystem service classifications (described in the sections that follow) provide the framework for the collection/collation of baseline environmental information. Their purpose is to ensure that evidence gathering and presentation is systematic and comprehensive and so supports development of a Sustainability Appraisal framework that is fit for purpose. It is recognised that there is a trade-off between the optimum level of detail required to provide the most complete natural capital assessment and the availability of resources to collect the necessary information. However, an initial participatory process with stakeholders as part of the scoping phase will quickly reduce the full framework to a subset that is appropriate for the plan/programme. Habitat and ecosystem service classifications in particular are hierarchical, and so can be expanded or collapsed according to the needs and scope of a specific context.

Description and discussion of the structure and content for the database and summary tables is given in the following sections. The main elements of the database are summarised in Figure 9, and the different components are introduced and explained in a logical progression, as the process for developing the asset register, ecosystem services inventory, asset-service matrix and risk register is outlined. A preliminary worked example that includes certain elements is included in the sustainability assessment for the North Devon Marine Natural Capital Plan (Appendix 2). Identification of a full suite of resources that can support data gathering to complete the database in particular contexts is beyond the scope of this guidance, but some indicative examples of such resources are given.

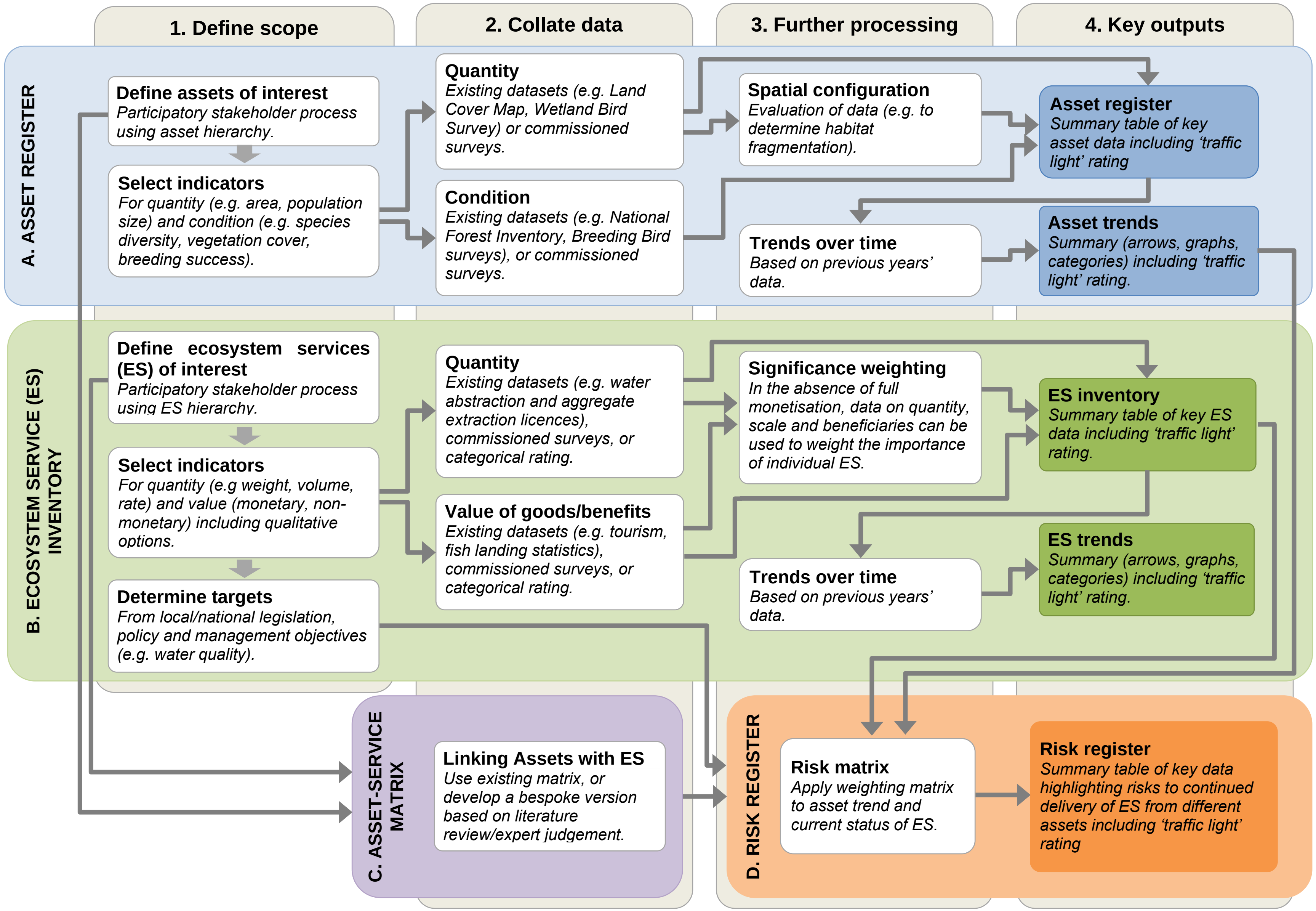


Figure 9. The main steps and elements of the natural capital assessment process and their outputs, which form the key elements of the sustainability appraisal database.

3 Set High Level Sustainability Objectives (Step 1)

3.1 The Five Capitals Model

Employing a natural capital approach has no effect on methods for identifying other relevant policies, plans and programmes, and so those components are not considered here. A natural capital framework is, however, pertinent to the identification of sustainability objectives.

Sustainability objectives will be specific to individual contexts, but in all cases these should seek to secure environmental improvements, an ethos encouraged by the 25 Year Environment Plan (HM Government, 2018) and the National Planning Policy Framework (MHCLG, 2019a). Sustainability objectives tend to be defined initially at a high level, for example ‘Promote sustainable tourism’ (Torridge District Council and North Devon Council, 2016a), ‘Protect and conserve natural resources’ (Lepus Consulting, 2019), or ‘Ensure resources are available and efficiently used to sustain development and reduce waste and consumption’ (Wood Environment & Infrastructure Solutions UK Limited, 2019).

Such high-level objectives are appropriate initially as a means of steering the general direction of the Sustainability Appraisal, but these need to be supported by detailed sustainability indicators defined within the final sustainability appraisal framework (Step 4), and developed following an iterative process undertaken as baseline information and sustainability issues are identified (Steps 2 and 3).

The Five Capitals Model (Figure 5) and overarching natural capital system concept (Figure 6) should be used to frame consultations around the key issues to be addressed by the sustainability objectives, and thus ensure that there are appropriate objectives that support the whole system. The five capitals model has already been applied to Sustainability Appraisal, for example in the creation of the Powys Local Development Plan (Powys County Council, 2017), and more widely during scoping in other planning contexts (e.g. Calne Town Council et al., 2012). Examples of how specific planning topics have previously been classified according to the type of capital represented are given in Table 2.

Table 2. Examples of topics relevant to each of the five capitals, in a local planning context (adapted from Powys County Council, 2017; with definitions from Forum for the Future, undated and Hattam et al., 2017).

Capital	**Natural**	**Manufactured**	**Human**	**Social**	**Financial**
Definition	Encompasses natural resources as well as the processes needed to sustain life and produce goods and services	Goods or assets that contribute to the production process or the provision of services, rather than being part of the output itself. It includes for example tools, machinery, buildings and infrastructure.	The health, knowledge, skills and capabilities of individuals	Networks together with shared norms, values and understandings that facilitate cooperation within or among groups (such as families, unions, schools, voluntary organisations)	Those assets of an organisation that exist in a form of currency that can be owned or traded, including shares, bonds and banknotes.
Examples	• Energy • Climate Change • Waste • Water • Green Infrastructure	• Housing • Access • Regeneration	• Health • Education • Skills • Employment	• Community support • Governance • Equality • Culture, Sense of Place • Business	• Maximising financial effectiveness

In practice, however, it may prove difficult to allocate high level plan/programme themes and objectives to a single type of capital, as they are likely to encompass a multitude of issues. The five capitals model is more useful in breaking down overarching aims into their constituent parts from which specific objectives, indicators and targets can be derived that encompass the environment, infrastructure, individuals and wider society.

For example, an aim to manage and adapt to climate change can be considered in terms of:

- the ability of the environment to sequester carbon and to protect infrastructure from flooding and erosion (*natural capital*)
- the availability and suitability of renewable energy infrastructure, public transport and flood protection infrastructure (*manufactured capital*)
- the required skills, employment opportunities and need to encourage behaviour change around e.g. transport use (*human capital*)
- the opportunity for community-led energy projects (*social capital*)
- mechanisms to encourage related inward investment (*financial capital*)

Examples of specific sustainability objectives for the different types of capital are given in Table 3.

Table 3. Examples of high-level sustainability objectives for each of the five capitals (Torridge District Council and North Devon Council, 2016a; Powys Council, 2017; Halcrow Group Ltd, 2009; Calne Town Council et al., 2012).

Main capital type	Examples of high-level sustainability objectives
Natural	• Protect and enhance biodiversity and important wildlife habitats • Protect and enhance the countryside, natural landscape and townscape. • Maintain and enhance heritage assets and their settings. • Maintain and enhance air quality. • Protect high-grade soils
Manufactured	• Provide suitable housing that meets the needs of the population and maximise affordable housing • Improve energy efficiency and use of sustainable construction materials • Make public transport, walking and cycling easier and more attractive • Ensure that new buildings are of a high quality both in main town centre areas and within the remainder of the town,
Human	• Provide access to learning, training, skills and knowledge for everyone • Diversify the range of local employment opportunities • Improve health of population and reduce health inequalities • Strengthen research, technology and innovation
Social	• Reduce crime and the fear of crime • Promote development which supports community wellbeing and cohesion, especially in those areas facing multiple deprivations • Use information technology to promote and facilitate opportunities within the community planning process including buildings and services which can be utilised by the community, using business networks to provide opportunities for new enterprise • Contribute to a diverse and growing population with a balanced demographic structure • Fully engage with and positively involve the local community and other interested parties at all stages of the planning process
Financial	• Foster sustainable economic growth • Contribute to a private sector that is a high-level economic contributor • Provide export opportunities • Become a location of choice for startup businesses

Although the full five capitals model has been presented here, only environmental inputs (Natural Capital, and Manufactured Capital where this relates to built heritage) will be discussed further in the remainder of this document. Wider issues related to, or attempts to classify, other capitals and other (non-environmental) services are beyond the scope of this guidance.

4 Collect Baseline information (Step 2)

4.1 Asset Register (Step 2.1)

The first constituent of the natural capital evidence base is an asset register, defined simply as "*an inventory of the natural assets in an area and their condition*" (Natural Capital Committee, 2017). Much of the development of the natural capital approach has been in relation to changes in land use, which can be mapped and are often amenable to remote-sensing approaches. This has led to a focus on habitats as key assets and the units which supply ecosystem services. There are limitations to this 'land cover' approach particularly for marine areas (Hooper et al., 2019a), but an alternative with the same level of understanding and acceptance has not yet been developed. Populations of mobile species are also important natural capital assets, and heritage assets should be considered. While heritage assets are not 'natural' capital, they are important environmental inputs to the socio-ecological system (and generate ecosystem services in tandem with ecological assets) and so should be included in the asset register.

4.1.1 Habitat classification hierarchy

Classification systems are designed to provide a consistent categorisation where there are multiple individual elements to be considered, and thus enable systematic and comparable assessment. It is therefore recommended that baseline information on habitats is collected using a recognised classification hierarchy. For terrestrial and freshwater natural capital assets, the UK Habitat Classification[2] (UKHab; UK Habitat Classification Working Group, 2018) is considered most appropriate as a framework for data collection and presentation. It is recommended to those intending to apply the Biodiversity Metric 2.0[3] (Crosher et al., 2019). Given the relevance of this metric to determining biodiversity net gain, which is expected to be mandated in the forthcoming Environment Bill (Defra, 2019), it seems probable that the UKHab will become familiar to, and widely used by, both planning authorities and developers. Furthermore, the scoring within the Biodiversity Metric 2.0 contains a weighting for strategic significance, recognising how strategic objectives should be explicitly linked to actions at a site scale. Using the same framework at the plan/programme scale supports identification of strategically significant assets to be considered in net gain assessment and planning/licensing decisions.

UKHab also links closely with the broad habitats from the UK National Ecosystem Assessment (2011), which are also those of the Countryside Survey (Maskell et al, 2008), the Land Cover Map (CEH, 2017) and Natural England's Natural Capital atlases (Wigley et al., 2020). Thus, the use of UKHab should facilitate access to extent and condition data associated with these national monitoring programmes and tools, further details of which are available from the relevant websites[4,5,6]. The UK National Ecosystem Assessment (2011) classification is also the basis of the ENCA framework (Defra, 2020), and so the straightforward translation between this and UKHab also facilitates linkages to accounts developed using the ENCA methodology.

An alternative classification system on which to base a natural capital assessment is the European Nature Information System (EUNIS[7]), which has been used for Scotland's Natural Capital Asset Index (Watkinson, 2017). EUNIS is a "*comprehensive pan-European system to facilitate the harmonised description and collection of data across Europe through the use of criteria for habitat identification"* (European Environment Agency, 2019). The EUNIS classification is commonly used for categorising coastal and marine areas, and is the basis of the UK[8] and EU[9] SeaMaps (Populus et al., 2017). The Biodiversity Metric 2.0 recommends the EUNIS classification for net gain assessment in intertidal areas (Alvarez et al., 2020), and it was also used in the Mapping and Assessment of Ecosystems and their Services (MAES) programme (Maes et al., 2013).

A drawback to using EUNIS in practice at more strategic scales is that the higher levels of the classification do not indicate the presence of important habitats. The Biodiversity Metric 2.0 has therefore created an additional category such that intertidal bedrock habitats (including peat/clay/chalk) will be identified (Alvarez et al., 2020). For this reason, the UKHab classification may be more appropriate in sustainability appraisal for coastal areas. UKHab links closely to priority habitats and therefore features such as seagrass and mussel beds, as well as chalk, peat and clay exposures, are highlighted. Also,

[2] https://ecountability.co.uk/ukhabworkinggroup-ukhab/
[3] http://publications.naturalengland.org.uk/publication/5850908674228224
[4] https://countrysidesurvey.org.uk/
[5] https://www.ceh.ac.uk/services/land-cover-map-2015
[6] http://publications.naturalengland.org.uk/publication/6672365834731520
[7] https://eunis.eea.europa.eu/habitats-code-browser.jsp
[8] https://jncc.gov.uk/our-work/marine-habitat-data-product-ukseamap/
[9] https://www.emodnet-seabedhabitats.eu/

UKHab facilitates use of Countryside Survey data, which provides information on temporal change in intertidal habitats.

UKHab, the Biodiversity Metric 2.0 and data sources such the Countryside Survey do not apply below the low water mark. Marine habitats are included within the UK National Ecosystem Assessment (2011) but this classification for coastal and marine habitats is not comprehensive (pelagic habitats are lacking) or consistent, as it mixes supralittoral (splash zone) and littoral (intertidal) habitats in one category (Hooper et al., 2019a). Therefore, EUNIS is a more appropriate classification for marine habitats, which again should facilitate the use of open-access marine habitat maps.

In developing an asset register for Sustainability Appraisal, it is recommended that the UKHab classification is used for terrestrial, freshwater and intertidal habitats and that EUNIS is used for fully marine areas. Both systems use expandable hierarchies, allowing the level of resolution required to be adapted to the context of the plan or programme being considered by the Sustainability Appraisal. It is expected that setting the scope for the Sustainability Appraisal will require consideration of habitats to Level 4 in both UKHab and EUNIS, even if detailed, systematic data and maps are not available for all habitats at this level of resolution. The high levels of the proposed classification for natural capital assets is given in Table 4, and the full classification in Appendix 3. Deep sea habitats (EUNIS category A6) and pelagic zones below the euphotic are not included as they are considered outside scope of this guidance. In principle, the approach should apply to all marine systems, but deep sea areas have particular challenges, and the proposed method should be evaluated in that specific context.

Published conversion tables exist to support understanding of correlations between different habitat classifications (e.g. UK Habitat Classification Working Group, 2018; JNCC, 2018). An example of cross tabulation between UKHab and EUNIS for intertidal habitats is also included in Appendix 3. The marine component of EUNIS is also begin updated, but the related documentation (EEA, 2019) contains correlation with the 2012 version (which is used in this guidance).

Table 4. Broad and component habitat types for assessment of natural capital assets in Sustainability Appraisal, (based on UK Habitat Classification Working Group, 2018; and EUNIS[6])

Zone	Broad Habitat	Component Habitat
Land	Grassland	Acid grasslands Calcareous grasslands Neutral grasslands Modified grassland
	Woodland and forest	Broadleaved, mixed and yew woodlands Coniferous woodlands
	Heathland and shrub	Dwarf shrub heath Hedgerows Dense scrub
	Wetland	Bog Fen, marsh and swamp
	Cropland	Arable and horticultural
	Urban	Built up areas and gardens
	Sparsely vegetated land	Inland rock Supralittoral rock Supralittoral sediment
Freshwater	Rivers and lakes	Standing open waters and canals Rivers and streams
Marine	Marine inlets and transitional waters	Littoral rock Littoral sediment
	Sublittoral habitats	Sublittoral rock Sublittoral sediment Pelagic water column

Abiotic assets

Natural capital assets also include abiotic elements which supply ecosystem services regardless of the presence of any living organisms, including:

- bodies of freshwater (used for drinking, irrigation, or navigation)
- mineral reserves (that supply e.g. gems or building aggregates)
- energy sources (peat stocks, as well as water/air as a source of e.g. tidal and wind flows)
- landscape features (such as caves, cliffs)

It is not expected that abiotic assets should be categorised separately from biotic assets (they can be combined together within the proposed habitat classifications) but the abiotic component of an asset needs to be recognised in determining the supply of ecosystem services (see Section 4.2 below).

4.1.2 Species and heritage assets

The UK National Ecosystem Assessment identifies the role of biodiversity in the provision of ecosystem services, and lists ten main species groups (Norris et al., 2011):

- micro-organisms
- fungi
- lower plants
- higher plants
- invertebrates
- fish
- amphibians
- reptiles
- birds
- mammals

However, the level of species diversity renders impractical the development of a manageable, generic framework for species similar to that for habitats. In determining key species assets therefore, it is proposed that a context-specific list is defined for each Sustainability Appraisal, which considers in particular protected species (including those defined in the Annexes of the Habitats and Birds Directives, or are otherwise features of terrestrial and marine protected areas), as well as those species that support ecosystem services such as food and recreation and/or have high non-use values (for example species of fish, birds and mammals). The habitats framework (Table 4) can also be used to direct thinking on the species present in these different areas. An example of a bespoke species list developed for Sustainability Appraisal is given in the case study for the Marine Natural Capital Plan (Appendix 2), which included wetland birds, seabirds, commercial fish and shellfish, protected marine and coastal plants and invertebrates, grey seals and harbour porpoise.

In the expanded natural capital system proposed, heritage assets become part of the environmental inputs to the system, to be considered in parallel with natural capital assets. The National Planning Policy Framework (MHCLG, 2019a) defines seven categories of designated heritage assets namely:

- World Heritage Site
- Scheduled Monument
- Listed Building
- Protected Wreck Site
- Registered Park/Garden
- Registered Battlefield
- Conservation Area

These provide a starting point for assessment, but the historic environment also includes non-designated heritage assets, encompassing locally significant buildings, monuments, sites, places areas or landscapes identified by Local Planning Authorities (MCHLG, 2019). The inclusion of non-designated assets is further reinforced in the Marine Policy Statement (HM Government, 2011a) for heritage assets in the marine environment. Thus, as with species assets, generic frameworks to support assessment of the full suite of heritage assets are not practicable and context-specific lists should be defined.

4.1.3 Database summary table

The natural capital evidence database is designed to be a summary of available information that facilitates reporting at the overarching scale of the sustainability appraisal. The key information required for an asset register is the extent (quantity), condition (quality) and spatial configuration of each asset (Table 5), and the use of maps and Geographical Information System (GIS) layers is encouraged (Natural Capital Committee, 2017).

Table 5. The format of the asset register summary table, with a description of the information required and suggested options/examples of cell content

Column header	Description	Options/*examples** for cell contents
Quantity	A quantified assessment of the area, volume or number of individuals (as appropriate).	*e.g.6.7km², 3,184 individuals*
Quantity trend	Where time series data is available or can be estimated, the broad trend in the quantity of the asset should be noted, which can be represented visually, e.g. as directional arrows.	Improving; Stable; Declining
Quality rating	Quality rating should be given on a categorical scale, which can be represented visually, e.g.as a traffic light system.	Poor; Moderate; Good
Quality trend	Where time series data is available or can be estimated, the broad trend in the status of the asset should be noted, which can be represented visually, e.g. as directional arrows.	Improving; Stable; Declining
Spatial configuration *(habitats only)*	The degree to which the asset is spatially coherent (i.e. occurs in patches of sufficient size to support effective ecological functioning, and has connections to other areas) and appropriately sited to provide ecosystem services.	Poor; Moderate; Good
Spatial configuration trend *(habitats only)*	Where time series data is available or can be estimated, the broad trend in the spatial status of the asset should be noted, which can be represented visually, e.g. as directional arrows.	Improving; Stable; Declining

* the associated categories/scales to be used in recording (given in normal type) or, where category lists are extensive or not applicable, examples of possible content (*in italics*)

Quantity is perhaps the most straightforward metric for which to gather data, particularly with the availability of remote sensing options and resources including the Land Cover Map[4] and, for intertidal and marine habitats, the UK[7] and EU[8] SeaMaps. Useful population data also exist for certain species (such as the Wetland Birds Survey[10]) and individual Local Authorities hold data on heritage assets in the form of Historic Environment Records[11]. Indicators for asset quality (and other metrics related to the natural capital approach) are included in Defra's consultation on measuring progress of the 25 Year Environment Plan (Defra, 2018), although the suite of indicators currently proposed has been criticised as being insufficient (Natural Capital Committee, 2019; 2020). A comprehensive assessment of indicators was undertaken by Natural England (Lusardi et al., 2018), which has been applied in the development of their national natural capital atlas (Wigley et al., 2020). Other suggestions for, and reviews of, indicators include those of Maes et al. (2018), Tillin et al. (2019) and Burdon (2020).

In determining the quality of assets, an existing formal quality assessment may be available, for example for protected sites that undergo statutory condition monitoring. Otherwise, literature providing guidance on conducting condition assessment is available. For example, Natural England's work in developing a biodiversity metric for net gain (Crosher et al, 2019) provides criteria against which terrestrial habitats (including coastal habitats found in the splash zone) should be judged for poor, medium or good status, and is designed particularly for the planning context. For the marine environment, Rees et al. (2019) propose a method for determining the Likely Relative Condition of marine habitats, based on knowledge of pressures occurring in an area and the sensitivity of habitats to those pressures. Quality information for species can include factors such as breeding success, which may be recorded as part of condition assessment for designated species. Some quality information may be available for heritage (for example, in the entry records for listed infrastructure), and this parameter can also be used to capture information about the setting of the asset.

The third component of natural capital status is spatial configuration, which applies only to habitats. Spatial configuration should be considered in terms of the extent to which the overall area of the habitat is fragmented, as this can significantly affect the ecological functions and hence any services or benefits provided (Mace *et al.*, 2015; Bateman *et al.*, 2011). Assessment of the spatial configuration should also

[10] https://bto.org/our-science/projects/wetland-bird-survey
[11] https://www.heritagegateway.org.uk

consider whether the asset is appropriately located for the provision of ecosystem services. The role of saltmarsh in providing coastal protection is likely to be site dependent (Shepard et al., 2011) and other habitats such as woodlands need to be in the right place to, for example, intercept pollution and hence improve environmental quality. There is not a straightforward and universally accepted mechanism for assessing spatial configuration, although the connectivity of habitats is considered within the Biodiversity Metric 2.0 (Crosher et al., 2019) and experimental indicators are being developed (JNCC, 2019). Therefore, for the purposes of the asset register, it is expected that a categorial rating will be used.

Information on temporal trends for asset quantity, quality and spatial configuration is also important for highlighting those assets most at risk and understanding the likely impacts of any plan or programme. An indicator that combines all three elements could be developed, although keeping the different facets separate aids understanding of whether sustainability issues relate to the loss or the degradation, or both, of natural capital and heritage assets. Maintaining the asset register in database form supports understanding of trends. Many plans and programmes (particularly local plans, marine plans, and some strategic environmental assessments such as that for offshore energy) are refreshed or repeated after an interval of several years. The systematic storage of data from previous assessments facilitates its comparison with updated information. Temporal change in asset quantity will be challenging to assess in marine habitats unless local monitoring is undertaken. Resources such as UKSeaMap use primarily modelled data and are not appropriate for determining trends in habitat cover.

The summary table should be supported by a wider narrative containing additional information about each asset, to aid understanding of the likely response of the asset to any change resulting from the plan/programme. Noting any conservation designations and other relevant management systems in place for particular assets will also support understanding of the interactions between the proposed plan/programme and existing policies. Further information related to the status of the habitat (such as reasons for declining quantity, poor quality or fragmentation; proximity to thresholds/tipping points; and comparisons with wider national trends) should be included, together with reference to any other factors that constrain, inform or otherwise affect aspects of resource use and management.

4.2 Ecosystem Services Inventory (Step 2.2)

4.2.1 Classification Hierarchy for Ecosystem Services

The next stage is to identify the ecosystem services important within the context of the plan/programme. As is the case for assets, a standard classification should be used to identify and categorise the services that will feature in the inventory. There has been some debate as to whether universal classification for ecosystem services is desirable or even possible (as reviewed in e.g. Hooper et al., 2019a). However, certain classifications have emerged that have been widely used in different circumstances, and thus demonstrated their applicability in practice as a framework to support natural capital assessment. The Common International Classification of Ecosystem Services (CICES; Haines-Young and Potschin, 2013; 2018) has been applied extensively outside the academic sector, particularly in Europe (La Notte *et al.,* 2017), including as the basis for Scotland's Natural Capital Asset Index (Watkinson, 2017). Alternative classifications are in development particularly to support ecosystem accounting, such as the National Ecosystem Services Classification System (NESCS) in the United States (United States Environmental Protection Agency, 2015). However, these have rarely been applied in practice.

CICES[12] was first published in 2013, and updated to its current version (5.1) in 2018. It provides a hierarchy of ecosystem services within the three broad sections of Provisioning, Regulation and Maintenance, and Cultural (further details of which are provided in Appendix 4). CICES includes the contribution of abiotic features, i.e. those aspects of the environment that provide services independent of species or habitats, such as marine aggregates as raw materials, and caves and rock faces used for recreation. It is thus compatible with the wider definition of environmental inputs as used in the overarching conceptual framework proposed in this guidance. In its definitions and examples, CICES

[12] https://cices.eu/

further seeks to reinforce that ecosystem services represent the ecological end point of the chain, and do not of themselves provide goods and benefits to people without further human interaction. Therefore, cultural services are described as “opportunities” for recreation and provisioning services are described in terms of, for example, standing crops and the harvestable proportion of stocks rather than as the quantity of food or raw materials that ultimately result.

CICES is designed to be a comprehensive and precise categorisation, with unambiguous, mutually exclusive categories. In practice, however it may be challenging to disentangle particular individual services (especially, for example, different cultural services obtained from indirect interactions) and so it may be necessary to assess these in aggregate. While CICES is a hierarchical classification, the higher levels of the classification (division, group) are perhaps not arranged in the most straightforward way from an end-user perspective. Therefore, the ecosystem services framework proposed for Sustainability Appraisal combines the individual CICES classes (the most detailed level of that hierarchy) with a higher level classification used by Natural England in the development of accounts for National Nature Reserves (Sunderland et al., 2018). In doing so, this provides more accessible categories for ecosystem service groups. The higher levels of this framework are shown in Table 6, with the CICES classes (Level 4 of the hierarchy) included in Appendix 4. The hierarchy also includes a provisioning category of ‘Carrier’ services to recognise the role of waterways in the transport of goods (following Hooper et al., 2014).

Table 6. The higher levels of the ecosystem service hierarchy proposed for supporting Sustainability Appraisal, (developed from Sunderland et al., 2018; Haines-Young and Potschin, 2018; Hooper et al., 2014).

Level 1	Level 2	Level 3
Provisioning	Food	Cultivated food crops Livestock Cultivated seafood Foraged plants Game and wild fish Food products from non-living sources
	Materials	Non-food products from plants, animals & algae Non-food products from non-living sources Genetic resources
	Water	Water supply
	Energy	Energy from non-living sources Energy from plants Energy from animals
	Carrier	Commercial and other transport
Regulation and maintenance	Environmental quality	Water quality Air quality Soil health
	Maintaining wild populations	Pollination & seed dispersal Maintenance of nursery populations and habitats
	Hazard and nuisance reduction	Erosion control Flood protection Storm protection Pest and disease control Fire protection Noise reduction Visual screening
	Climate regulation	Climate regulation
Cultural	Physical, experiential and intellectual interactions	Recreation, tourism and other experiential opportunities Scientific and educational opportunities
	Cultural significance of nature	Aesthetic Heritage, spiritual and representational significance
	Non-use values	Existence, bequest and option values

The categories listed Table 6 can be used as the main scoping framework, but further reference to the full CICES list (Appendix 4) should also be made, as this will serve to highlight services that are important but may not be immediately obvious (as is often the case for regulating services in particular). As with the identification of key assets, a participatory process with stakeholders should quickly identify services that are not applicable or are not provided in a significant quantity, and hence allow the list to be refined for the context of a specific Sustainability Appraisal.

4.2.2 Database summary table

Ecosystem services should be recorded separately in the database in the format suggested in Table 7. Again, a wider narrative is also required, in particular to capture additional information such as who are the beneficiaries of particular services, which can link to other aspects of the plan/programme related to human and social capital. The first requirement for the summary table is to document information about the quantity and trend of the ecosystem service itself. It is important to remember the distinction between ecosystem services (the ecological endpoint) and goods/benefits (access to which requires human intervention). For example, the presence of harvestable woodland and stocks of edible fish are services, while timber and landed seafood are the goods that result from exploiting these services. The quantity of a particular ecosystem service delivered is therefore likely to be in physical units representing, for example, an area, volume or rate. The work at a national level to develop natural capital indicators (Defra, 2018; Lusardi et al., 2018; Wigley et al., 2020) includes those for ecosystem services, and further recent work has been undertaken with a particular focus on cultural services and heritage (Burdon, 2020).

Where appropriate, targets related to the ecosystem services should also be recorded. These are likely to include existing policy targets (such as those specifying minimum standards for bathing water quality), which should have been determined as part of the first Sustainability Appraisal scoping step to identify other relevant policies, plans and programmes. Details of the specific target should be recorded, but this should also be converted for the purposes of the summary table to a rating reflecting whether the service is at, below or substantially below the target (as proposed by Mace et al., 2015). This will highlight potential sustainability issues and also links directly to inputs for the risk register (Section 5).

Table 7. The format of ecosystem service inventory summary table, with a description of the information required and suggested options/examples of cell content

Column header	Description	Options/*examples** for cell contents
Quantity	A quantified assessment where possible of the quantity of the service (which may be an area, volume or rate).	*e.g.93 tonnes/year*
Trend	Where time series data is available or can be estimated, the broad trend in the supply of the service should be noted, which can be represented visually, e.g. as a traffic light system or directional arrows.	Improving; Stable; Declining
Target	A categorical rating scale to demonstrate whether the service is being delivered at an acceptable level.	At/above target; Below target; Substantially (>50%) below target
Value of goods/benefits	Monetary value can be provided where available.	*e.g.£480,906*
Significance	Where monetary value for benefits is not available, an indicative rating of the significance of the service should be given on a categorical scale, which can be represented visually, e.g.as a traffic light system.	Low; Moderate; High
Risk rating	A categorical rating scale that indicates the degree to which continued delivery of the service is at risk (*to be completed following compilation of the risk register*)	Low; Moderate; High

* the associated categories/scales to be used in recording (given in normal type) or, where category lists are extensive or not applicable, examples of possible content (*in italics*)

The value of the goods/benefits arising from the service should also be recorded. Market data on the quantity and monetary value of goods and benefits such as fish and timber and for tourism and recreational activities are potentially already published or relatively easy to obtain (e.g. the Marine Management Organisation provides data on the quantity and value of fish landings from particular areas and/or into particular ports). Obtaining monetary values for non-market benefits arising from ecosystem services can be costly and time consuming. However, a growing number of studies have sought to determine these values. Reviews of these exist (such as, for marine, Torres and Hanley, 2017, and Hooper et al., 2019), and other sources of valuation data are provided within ENCA[13] (Defra, 2020). Online databases include the Environmental Valuation Reference Inventory[14], and the Environmental Value Look-up Tool prepared for Defra (eftec, 2015). The latter was developed in the specific context of increasing the use of environmental valuation in Government appraisals, and it is organised around the UK National Ecosystem Assessment broad habitat categories. Where published values have not been obtained in the same context as that underlying the Sustainability Appraisal, it may be possible to apply a value transfer (or benefits transfer) approach to apply the value in the new situation (eftec, 2009).

Monetary valuation of changes in natural capital has been promoted as a means to support decision making processes because it can provide a common metric for comparison (Natural Capital Committee, 2013). This remains true, but it is similarly asserted that "*monetary valuation is problematic or incomplete for a broad suite of ecosystem services*" (Chan et al., 2012, p14). In the context of the natural capital approach in Sustainability Appraisal, there is no expectation that all goods and benefits will be monetised. Instead, a categorical rating of the importance of the service, based on the scale of supply and types of beneficiary can be used to indicate the significance of particular services.

The risk rating category for the summary table shown here for convenience, but it will be completed after the risk register has been compiled (see Section 5).

4.3 Asset-Service Matrix (Step 2.3)

It is also important in the scoping phase of a Sustainability Appraisal to make the connection between the ecosystem services and the assets from which they are generated. This is necessary to ensure that the proposed plan/programme does not affect the assets in a way that jeopardises the continued delivery of services and benefits. Furthermore, the process will highlight those assets that require prioritisation due to the type and level of ecosystem services they provide but which may lack protected status. Local Plans often include sustainability objectives that are not explicitly linked to the environment, but are supported by ecosystem services (e.g. tourism, health and wellbeing, climate change adaptation). Therefore, understanding how these are delivered is fundamental in supporting objectives and options that are coherent across the plan.

The proposed approach is to generate an asset-service matrix that highlights the degree to which the assets present in the plan/programme area provide ecosystem services. This will form a further sheet in the database, supporting the asset register and ecosystem service inventory. The key component of the matrix is the level of service provision, with a categorical scale used to indicate the degree to which a particular asset generates a particular ecosystem service. Table 8 provides an example of an asset-service matrix taken from Scotland's Natural Capital Asset Index (Watkinson, 2017). This uses a five point scale (in addition to a 'no relevant potential' category). However, a three point scale (low, moderate, high) may be more practicable with constrained resources. The process of developing the asset-service matrix may highlight the presence of ecosystem services that were not initially apparent (particularly in the case of regulating services), which may require the ecosystem services inventory to be modified.

These linkages between assets and services may be clear (such as how the presence of certain bird or mammal species supports recreational wildlife watching activities), and the knowledge of local stakeholders will be important at this stage. However, it is expected that there will be a limit to the extent

[13] https://www.gov.uk/government/publications/enca-featured-tools-for-assessing-natural-capital-and-environmental-valuation
[14] http://www.evri.ca/

of stakeholder knowledge (particularly for regulation and maintenance services such as mediation of hazards and climate regulation) and so additional reference to literature will be required. Published matrices such as that used in Scotland's Natural Capital Asset Index (Watkinson, 2017), the original work on which it is based (Burkhard et al., 2014), and detailed marine examples (Potts et al. 2014, Burdon et al., 2017) are a useful starting point for a specific Sustainability Appraisal. However, they provide a generic assessment of ecosystem service potential (i.e. what the asset has the capacity to deliver), which may not be what is actually delivered in the context of the plan/programme. Where assets are degraded, for example, they may not be providing the expected level of ecosystem services.

A further limitation of published matrices is that they do not use a consistent underlying framework; they may use EUNIS habitats at different levels, or ecosystem services classifications that predate CICES v5.1. Thus, there is likely to be the need to translate the published information to better fit the Sustainability Appraisal framework. The full adapted versions of published matrices are included in the spreadsheet that supports this document.

Table 8. An excerpt from the table of ecosystem service potential contained within the model used for Scotland's Natural Capital Asset Index (Watkinson, 2017)

Key: Ecosystem service potential

0	No relevant potential
1	Low relevant potential
2	Relevant potential
3	Medium relevant potential
4	High relevant potential
5	Maximum relevant potential

	PROVISIONING					REGULATION AND MAINTENANCE							CULTURAL		
	Cultivated crops	Reared animals and their outputs	Water for drinking purposes	Materials from animals, plants and algae (for direct use or processing)	Plant-based energy sources	Mediation of waste, toxins and other nuisances (by biota)	Mediation of mass flows and erosion	Mediation of liquid flows (hydrological cycle/flood protection)	Pollination and seed dispersal	Maintenance of nursery populations and habitats	Soil formation and composition	Global, regional and micro-climate regulation	Physical and experiential interactions	Heritage, scientific and educational interactions	Aesthetic and entertainment interactions
B. COASTAL HABITATS															
B1 Coastal dunes and sandy shores	1	1	0	0	0	1	5	5	3	2	2	1	5	4	5
B2 Coastal shingle	1	1	0	0	0	1	5	5	3	2	2	1	5	4	5
B3 Rock cliffs, ledges and shores, including the supralittoral	0	1	0	0	0	0	3	1	0	1	0	0	3	3	3
C INLAND SURFACE WATERS	0	0	5	1	1	5	3	5	1	4	3	2	5	4	5
E. GRASSLANDS AND LANDS DOMINATED BY FORBS, MOSSES OR LICHENS															
E1 Dry grasslands	0	3	0	1	0	2	4	2	3	1	4	4	3	4	3
E5 Woodland fringes and clearings and tall forb stands	0	2	0	1	2	2	4	3	4	2	3	3	3	4	3
E7 Sparsely wooded grasslands	1	5	0	1	2	4	4	2	4	2	3	2	2	3	2
G. WOODLAND, FOREST AND OTHER WOODED LAND															
G1 Broadleaved deciduous woodland	0	2	0	5	5	4	5	4	4	4	5	5	5	5	5
G3 Coniferous woodland	0	1	0	5	5	4	5	4	4	4	5	5	5	5	5
G6 Exotic woodland and scrub	0	1	0	2	3	3	3	2	2	1	2	3	3	4	3
H. INLAND UNVEGETATED OR SPARSELY VEGETATED HABITATS															
H2 Screes	0	0	0	0	0	0	2	1	0	0	1	0	3	3	3
H3 Inland cliffs, rock pavements and outcrops	0	0	0	0	0	0	2	1	0	0	1	0	3	3	3
I. CULTIVATED AGRICULTURAL, HORTICULTURAL AND DOMESTIC HABITATS															
I1 Arable land and market gardens	5	1	0	3	3	3	1	1	4	1	1	2	1	2	1
I2 Cultivated areas of gardens and parks	2	1	0	2	1	3	1	1	4	2	2	2	3	2	3

As for all information reported in the database, it is important to record the sources used in constructing the matrix, which are likely to include stakeholder consultations and expert judgement as well as published peer-reviewed and grey literature. The quantity and quality of sources used will affect the level of confidence in the stated connections between assets and services. Ideally, this confidence should be reported in the matrix, and once again a three point scale (low, moderate, high) will suffice. An example of a matrix including a confidence assessment is given (Table 9), in which the confidence level depends primarily on the type of publication and its geographic origin. Confidence scales that provide a rating based on the quantity of evidence and the level of agreement between sources would also be appropriate, such as those used in Rapid Evidence Assessment (e.g. Collins et al., 2015).

Table 9. An excerpt from an assets-services matrix that includes a confidence rating (from Potts et al., 2014)

Key: *Relative ecosystem service contribution:* ■ Significant contribution ■ Moderate contribution □ Low contribution □ Not assessed *Confidence:* 3 UK-related, peer-reviewed literature 2 Grey or overseas literature 1 Expert opinion	Larval / Gamete supply	Natural hazard regulation	Regulation of water & sediment quality	Carbon sequestration
Intertidal mud	3	3	3	3
Coastal saltmarshes and saline reedbeds	3	3	3	3
Estuarine rocky habitats	1	1		
Blue Mussel beds	1	1	3	1
Honeycomb worm *Sabellaria alveolata* reef	1	2	1	1
Mud habitats in deep water	3	3	1	
Native Oyster *Ostrea edulis* beds	1	1	1	1
Kelp and seaweed communities on sublittoral sediment	1	1	1	1
Seagrass beds	1	1	2	2

5 Identify Sustainability Issues (Step 3)

5.1 Develop a Risk Register

The central component of the method proposed for identifying sustainability issues and problems is to compile a risk register, which is used to connect the continued delivery of ecosystem services with the status of natural capital assets. It thus identifies those assets at greatest risk from current human activity, allowing their management to be prioritised (Natural Capital Committee, 2013). As with all elements of the natural capital approach, examples of risk registers are few, but include Rees et al. (2019), and Lovett et al. (2018), as well as the preliminary high level assessment at the national scale prepared by Mace et al. (2015), on which the other examples are based.

The methodology proposed by Mace et al. (2015) has four preliminary steps:

(i) define natural asset classes;
(ii) determine trends in asset status;
(iii) determine asset-benefit relationships; and
(iv) establish targets and acceptability limits.

These steps will have already been completed, with the natural capital asset classes relevant to the plan/programme defined at the start of the process (Sections 4.1.1 and 4.1.2), and the trends in asset status also already recorded in the asset register (Section 4.1.3). Mace et al. (2015) propose using asset-benefit relationships in the risk register, but the recommendation here is that asset-service relationships are used. This is because service delivery is connected more directly to asset status; and the value of benefits can be affected by wider issues that are not related to the health of the environment (wider market trends, for example). These asset-service relationships have also already been defined in the asset-service matrix (Section 4.3), and targets for ecosystem service delivery form part of the ecosystem service inventory (Section 4.2.2). The risk to the continued delivery of the service is then determined, for each asset-service pair according to the criteria in Table 10, and recorded in the database as high, medium or low.

Table 10. The criteria for rating risks to the continued delivery of benefits as low, medium and high (adapted from Mace et al., 2015)

		Status of service		
		Above, or at, target	Below target	Substantially below target (>50%)
Trend in asset status	Positive or not discernible	Low	Medium	Medium
	Negative	Medium	Medium	High
	Strongly negative	High	High	High

Mace et al. (2015) proposed that the risk register be compiled for all three dimensions of the asset status: the quantity, quality, and spatial configuration, as changes to each of these has the potential to affect the generation of ecosystem services and the delivery of benefits. In practice, there will be limitations on the availability of evidence and so this may not be possible for all assets or services. An example of a summary table from a risk register is given in Table 11. An overall risk rating for each service should be added to the summary table for the ecosystem service inventory (Section 4.2.2), which will be derived from amalgamating the ratings across the different asset types. Amalgamation can be achieved by, for example, taking a precautionary approach (with the highest risk category from an individual asset being used to represent the service as a whole) or by using the most common risk rating. As before, the summary tables should be supported by a narrative that includes discussion of how evidence gaps may have led to the omission of certain assets or services from the risk register and any known risks associated with these.

Table 11. An excerpt from an example risk register output, showing risks associated with the three components of asset status: quantity (*Qun*), quality (*Qul*) and spatial configuration (*Sp*) (from Mace et al., 2015)

	Enclosed farmland			**Woodlands**			**Freshwaters**			**Coastal margins**		
	Qun.	*Qul.*	*Sp.*	*Qun.*	*Qul.*	*Sp.*	*Qun.*	*Qul.*	*Sp.*	*Qun.*	*Qul.*	*Sp.*
Food												
Fibre												
Energy												
Clean water												
Clean air												
Recreation												
Aesthetics												
Hazard Protection												
Wildlife												
Equitable climate												

Risk level: ☐ Low ☐ Medium ☐ High ☐ No significant relationship/no available information

Lighter shading indicates increasing uncertainty

5.2 Linking to wider plan/programme objectives and actions

For the purposes of Sustainability Appraisal, the risk register needs to link to the wider plan/programme objectives rather than simply providing a generic assessment of where asset status is of concern, so that (i) appropriate sustainability objectives can be defined; and (ii) to highlight (and hence amend) wider plan objectives that may contradict those related to natural capital aspirations. Making this connection includes the need to understand the pressures to which assets are vulnerable, and the ongoing or proposed activities within the context of the plan/programme to which the Sustainability Appraisal relates. Tools such as the Marine Biological Association's Marine Evidence and Sensitivity Assessment (MarESA[15]) provide an online resource for determining the sensitivity of marine habitats to pressures, allowing the compilation of a matrix that details the different impacts affecting the individual assets and ecosystem services. This can be summarised in a similar format to that suggested in Table 12.

Table 12. The sources of impacts on selected marine assets and ecosystem services, based on information from the South West Marine Plan scoping process (MMO, 2016a)

	Coastal defence erosion, development	Commercial fisheries	Industry, other activities	Marine litter, pollution, noise	Recreation, tourism	Renewables, other energy	Climate change
Natural Capital Assets							
Intertidal							
Subtidal							
Coastal Lagoons							
Mudflat							
Saltmarsh							
Sand dwelling species							
Shellfish							
Protected sites							
Mobile species							
Basking sharks							
Cetaceans							
Fish							
Marine mammals							
Marine megafauna							
Plankton							
Seabirds							
Seals							
Turtles							
Waterbirds							
Protected species							
Cultural services							
Leisure and recreation							
Visual amenity							

6 Develop the Sustainability Appraisal Framework (Step 4)

The Sustainability Appraisal framework requires the identification of sustainability objectives and indicators by which progress towards these objectives can be measured. The ultimate purpose of compiling an asset register, ecosystem service inventory and risk register is to summarise the current state of the environment within the plan/programme area and hence allow sustainability issues to be identified. The key outputs from these preliminary stages of the Sustainability Appraisal are:

- The current status of habitats, species and heritage assets in terms of quantity, quality and (for habitats) spatial connectivity
- Trends in this status over time
- The level of, and trend in, delivery of ecosystem services, and the value of the benefits arising
- The key areas of risk to the continued delivery of ecosystem services

[15] https://www.marlin.ac.uk/evidence

These are mostly presented as categorical summaries with 'traffic light' coding so that areas of potential concern can be easily identified, and are enhanced by summaries of the evidence and a wider narrative. These outputs therefore provide useful materials to support the process of defining detailed sustainability objectives that relate to specific natural capital assets and ecosystem services.

Examples of detailed sustainability objectives are shown in Table 13, which cover natural and other capitals to illustrate interconnection between the issues (such as engaging recreational users to support behaviour change, and the link between sustainable resource use and secure incomes). Under the expectations of the new Environment Bill, sustainability objectives could also be developed that explicitly identify assets that are considered strategically significant and should be prioritised for net gain. The process of gathering baseline information will have identified indicators for assets and services that are appropriate in the local context and can be used to monitor progress against the sustainability objectives. Programmes of ongoing data collection to support this monitoring will also have been identified. The identification of indicators is the final component of the sustainability framework. An example of indicators for the natural capital objectives of the North Devon Marine Natural Capital Plan is given in Table 14.

Table 13. The sustainability objectives from the sustainability appraisal for the North Devon Marine Natural Capital Plan (from Hooper et al., 2020)

Natural Capital (including related heritage)
• Disturbance of waterbirds, sea birds and marine mammals is reduced • All mussel beds in the Taw Torridge estuary rated at least Class B by 2030 • All designated bathing waters reach guideline standards by 2025 • All estuarine and coastal water bodies reach appropriate standards under the Water Framework Directive • Commercial stocks of fish and shellfish (wild capture) increase • Stocks of salmon and sea trout are maintained above their conservation limits • Health of fish habitats is maintained and where possible improved • Disturbance of intertidal mudflats in the Taw Torridge estuary from recreational bait collection (bait digging, crab tiling) is reduced • The quantity of plastic waste and litter on beaches and in the water column is reduced • Carbon storage capacity of the Taw Torridge estuary is increased • Disturbance (scour) of subtidal sediments is reduced • Levels of protection for environmental assets are maintained and where possible improved • Environmental quality in protected areas reaches at least minimum acceptable status • Likely relative condition of subtidal habitats is maintained and where possible improved • The cultural heritage value of ongoing inshore fisheries is maintained
Human Capital
• Employment opportunities increase in mariculture, shellfish hand-harvesting, and value-added activities for wild capture fisheries, where these do not exceed levels of sustainable exploitation • Local people are motivated to take part in environmental initiatives • Members of the public are motivated to improve their behaviour around waste disposal • Recreational users are motivated to improve their behaviour in order to minimise environmental disturbance • Fishers and harvesters are more engaged in sustainable fisheries management
Social Capital
• Networks for sustainable management of coastal and marine areas are strengthened • Recreational users are more engaged with sustainable management • Conflict amongst marine users is reduced • The use of citizen science data in decision making is increased
Manufactured Capital
• New infrastructure for renewable energy and mariculture conforms to sustainability criteria • New mooring infrastructure is installed to reduce habitat damage due to anchoring and scour from traditional moorings
Financial Capital
• Incomes for fishers/harvesters using low-impact techniques are maintained, and where appropriate increased, through sustainable management of resources and value-added activities • The economic contribution of recreation and tourism linked to marine and coastal natural capital is maintained • New financial mechanisms and products are established to support maritime activities and environmental protection

Table 14. The sustainability objectives and indicators from the natural capital elements of the sustainability appraisal for the North Devon Marine Natural Capital Plan (from Hooper et al., 2020)

Objectives	Indicators
Disturbance of waterbirds, sea birds and marine mammals is reduced	Number of disturbance incidents (from disturbance surveys)
All mussel beds in the Taw Torridge estuary rated at least Class B by 2030	Annual rating of shellfish water quality
All designated bathing waters reach guideline standards by 2025	Annual rating of bathing water quality
All estuarine and coastal water bodies reach appropriate standards under the Water Framework Directive	Annual water body status rating
Commercial stocks of fish and shellfish (wild capture) are within safe biological limits, and where possible are increased	(i) Stock sizes for, particularly, herring, bass, whelk, squid, skates and rays; (ii) Extent of Taw Torridge mussel beds; (iii) Size structure of Taw Torridge mussel beds
Stocks of salmon and sea trout are maintained above their conservation limits	(i) Catch per unit effort (from stock surveys) (ii) Stock status category
Health of fish habitats is maintained and where possible improved	Extent and condition of spawning and nursery habitats
Disturbance of intertidal mudflats in the Taw Torridge estuary from recreational bait collection (bait digging, crab tiling) is reduced	Size of disturbed area (from aerial photography)
The quantity of plastic waste and litter on beaches is reduced	Quantity of litter removed from beaches
Carbon storage capacity of the Taw Torridge estuary is increased	Extent/condition of saltmarsh (from aerial photography/LiDAR)
Disturbance (scour) of subtidal sediments is reduced	(i) Frequency of anchoring within restricted zones (from aerial photography) (ii) Area of scoured seabed around moorings (from surveys)
Levels of protection for environmental assets are maintained and where possible improved	(i) Percentage area within designated and voluntary marine protected areas; (ii) Percentage area protected by management measures;
Environmental quality in protected areas reaches at least minimum acceptable status	Condition assessment in protected area monitoring reports
Likely relative condition of subtidal habitats is maintained and where possible improved	Intensity of fishing and other activities (e.g. aggregate extraction) that impact on the seabed
The cultural heritage value of ongoing inshore fisheries is maintained	Number of licenced inshore fishing vessels

7 Evaluation of effects and alternatives (Step 5)

7.1 Developing a framework for comparing plan/programme options

The sustainability objectives provide the basic framework against which to evaluate overarching plan/programme policies and delivery options. Typical Sustainability Appraisal outputs include tables in which the relative magnitude of positive/negative impact upon each objective by each policy or option is indicated (e.g. Torridge District Council and North Devon Council, 2016b,c). Using a natural approach to sustainability appraisal as described in the steps described above will ensure that the sustainability objectives are explicit and relate to specific assets and ecosystem services. Having appropriately focused objectives (rather than those referring to environmental issues in vague or general terms), will facilitate more robust evaluation of likely impacts, and so support decision making that improves environmental outcomes.

Other approaches to Sustainability Appraisal go further, and compare the impacts of different plan/programme options on the individual receptors identified within the scoping process. Although this more detailed approach is likely to be more resource intensive, it was used in the Sustainability Appraisal for the South West Marine Plan, which considered 254 individual options across its 29 themes (see Appendix 1). Presenting summary information in a visual way (Figure 10) is likely to be beneficial in highlighting important trade-offs and thus supporting a participatory process for evaluating the different options and selecting which to take forward in the final plan/programme.

		Policy Option A		Policy Option B		Policy Option C	
SA Topic	**SA Sub Topic**	Significance	SA Database Topic Identifier	Significance	SA Database Topic Identifier	Significance	SA Database Topic Identifier
Cultural heritage	Heritage Assets within marine plan areas	Not Significant		Uncertain (Dependent on Implementation)	Cultural_178	Uncertain (Lack of Evidence)	
	Heritage Assets adjacent to marine plan areas	Not Significant		Uncertain (Dependent on Implementation)	Cultural_178	Uncertain (Lack of Evidence)	
Seascape and landscape	Effects on seascape and landscape	Significant Negative	Landscape_170	Uncertain (Dependent on Implementation)	Landscape_170	Uncertain (Dependent on Implementation)	Landscape_170
Water	Pollution and water quality	Significant Negative	Water_286, Water_14	Significant Positive	Water_286, Water_14	Uncertain (Dependent on Implementation)	Water_286, Water_14
	Marine litter	Significant Negative	Water_14, Water_288	Significant Positive	Water_14, Water_288	Uncertain (Dependent on Implementation)	Water_14, Water_288
Communities, health and well being	Health and wider determinants of health Effects on communities	Not Significant		Uncertain (Dependent on Implementation)	Communities_55, Communities_46, Economy_482	Uncertain (Dependent on Implementation)	Communities_55, Communities_46, Economy_482
Economy	Ports and shipping	Not Significant		Uncertain (Lack of Evidence)	Economy_578, Economy_620	Uncertain (Dependent on Implementation)	Economy_578, Economy_620
	Leisure / recreation	Not Significant		Significant Positive	Economy_481, Economy_482	Uncertain (Dependent on Implementation)	Economy_481, Economy_482
	Tourism	Not Significant		Significant Positive	Economy_481, Economy_482	Uncertain (Dependent on Implementation)	Economy_481, Economy_482
Biodiversity, Habitats, Flora and Fauna	Protected sites and species	Significant Negative	Biodiv_465	Significant Positive	Biodiv_465	Uncertain (Dependent on Implementation)	Biodiv_465
	Marine mega fauna	Significant Negative	Biodiv_465	Significant Positive	Biodiv_465	Uncertain (Dependent on Implementation)	Biodiv_465
	Ornithology	Significant Negative	Biodiv_465	Significant Positive	Biodiv_465	Uncertain (Dependent on Implementation)	Biodiv_465

Figure 10. An extract from the marine plan areas Sustainability Appraisal scoping report database (MMO, unpublished data)

Where resource allows, a detailed approach similar to that taken for the South West Marine Plan is recommended. The framework described above should be carried through into this phase of developing and refining alternatives; i.e. the implications of different plan/programme options should be considered against the constituent natural capital elements used in the scoping phase (e.g. assets, ecosystem services, benefits). In reporting, it is again suggested that summary tables are provided, using a 'traffic light' (or similar) system to report how the plan/programme options affect the different natural capital assets, services and benefits, as in the example below from North Devon Marine Natural Capital Plan (Table 15).

Table 15. An example output showing how the implications of plan/programme options on assets, ecosystem services and benefits, and human, social, and financial capital could be presented (based on and plan vs no plan scenario, and taken from Hooper et al., 2020)

Key:

Strongly positive		Neutral		Strongly negative	Not assessed
Dark green	Light green	Orange	Red	Dark red	Grey

	Short term (1-5yrs)	Longer term (>5yrs)
Natural capital assets		
Geology	Orange	Orange
Supralittoral rock	Orange	Orange
Supralittoral sediment	Orange	Orange
Littoral rock	Orange	Orange
Littoral sediment	Orange	Light green
Saltmarsh	Light green	Dark green
Mussel beds	Orange	Light green
Sublittoral rock	Orange	Orange
Sublittoral sediment	Orange	Light green
Commercial finfish	Orange	Light green
Crab and lobster	Orange	Orange
Wetland birds	Orange	Light green
Seabirds	Orange	Orange
Marine mammals	Orange	Orange
Heritage assets		
Designated and non-designated sites	Orange	Orange
Ecosystem services and benefits		
Cultivated seafood	Orange	Light green
Foraged plants	Orange	Orange
Game and wild fish	Orange	Light green
Non-food products from plants, animals & algae:		
Bait	Orange	Red
products from cultivated macroalgae	Orange	Light green
Genetic resources (*mussel spat*)	Orange	Light green
Energy from non-living sources (*tidal energy*)	Orange	Light green
Commercial and other transport	Orange	Orange
Water quality	Orange	Light green
Maintenance of nursery populations and habitats	Light green	Dark green
Erosion control	Grey	Grey
Flood protection	Grey	Grey
Climate regulation	Light green	Light green
Recreation, tourism and other experiential opportunities	Orange	Orange
Scientific and educational opportunities	Dark green	Dark green
Aesthetic	Light green	Light green
Heritage, spiritual and representational significance	Orange	Orange
Existence, bequest and option values	Light green	Light green
Social and human capital		
Community networks	Light green	Light green
Knowledge, skills and capabilities	Dark green	Dark green
Financial capital		
Inward investment	Light green	Dark green

In addition to traffic light coding, full reporting should also accommodate notation such as that used within the South Marine Plan Sustainability Appraisal to indicate the direction and magnitude of impacts arising from the different options, the type and reversibility of effects, and the level of confidence in the predictions (Table 16). Any such notation, and other outputs for reporting purposes, must take account of the requirement in the SEA Directive to include secondary, cumulative, synergistic, short, medium and long-term, permanent and temporary, positive and negative effects.

Table 16. The notation used to report changes from baseline conditions resulting from marine plan options for the South Marine Plan area (Ramboll Environ et al., 2018)

Notation	Description
Degree to which baseline conditions may change (significance of change) compared with the future baseline situation	
++	**Major Positive Effect (significant positive)** The plan is likely to lead to significant improvements in baseline conditions.
+	**Minor Positive Effect** The plan is likely to lead to some improvements in baseline conditions.
0	**Neutral Effect** The plan is unlikely to alter baseline conditions significantly.
-	**Minor Negative Effect** The plan is likely to lead to a deterioration in baseline conditions.
--	**Major Negative Effect (significant negative)** The plan is likely to lead to a significant deterioration in baseline conditions.
+/-	**Positive and Negative Effect** The plan is likely to lead to both a deterioration and an improvement in baseline conditions, perhaps in different areas or ways.
?	**Uncertain Effect** It is not known whether the plan would lead to an improvement or deterioration in the baseline conditions.
Degree to which baseline conditions may change (significance of change) compared with the future baseline situation	
Direct / Indirect	
D	Direct effect
I	Indirect effect
Reversibility of effects	
R	It is considered that the effects upon the receptor group could be reversed if activities were to change in the future. The receptor may hence be able to recover or indeed improvements could be diminished.
IR	It is considered that the effects upon the receptor group could not be reversed and would be permanent. This may apply to situations where, for example, features are destroyed for ever or systems/trends are irrevocably changed.
Certainty of prediction / Likelihood	
H	There is a high level of confidence in the assessment prediction. No identified data gaps.
M	There is a medium level of confidence in the assessment prediction. This means that the appraiser is largely certain of the direction of impact and some of the elements of prediction but there remains some doubt or certainty about some other elements.
L	There is low level of confidence in the assessment prediction. This may be as a result of significant baseline data gaps, there being very little control over how an activity may come forward or there is limited evidence to support the prediction.

It is not proposed that a set of natural capital accounts is included within the Sustainability Appraisal, but where monetary values are available option appraisal could take the form of a preliminary cost benefit analysis. However, as it is expected that the availability of monetary values will be limited, care should be taken with this approach. It would be appropriate to attempt to assess value change in this manner where consistent values are available across the different plan/programme options, and so any such assessment is more likely to be in the context of market values such as for fisheries, tourism or energy. Where monetary values are not available, other metrics can be used including quantitative data to document change in quantity supplied, or qualitative information that documents relative importance.

It is known that members of the public do not respond well to natural capital terminology (e.g. FM3, 2010) and so a modified typology may be required for outputs of the Sustainability Appraisal that are intended more specifically for a non-technical audience, such as the report cards produced as part of the Marine Plan Sustainability Appraisal process (MMO, 2016b).

8 Conclusions

The different elements of the process described above provide the framework for applying a natural capital approach to Sustainability Appraisal. Compilation of the asset register, ecosystem service inventory and risk register (and the wider evidence base) will show the current status and trends in assets, ecosystem services and benefits, the degree to which they are at risk and the activities most likely to impact upon them. This provides a comprehensive and systematic baseline against which to assess the implications of a plan/programme. This process also identifies the key sustainability issues and so allows the definition of sustainability objectives explicitly for natural capital assets and ecosystem services (as opposed to the general and high level objectives that are often used in current sustainability appraisals).

The proposed process helps to fulfil the Natural Capital Committee's call for a methodology for baseline natural capital assessments at a local level (Natural Capital Committee, 2019). The framework developed has the potential to support consents and licensing decisions based on Environmental Impact Assessment, as well as Sustainability Appraisal and other elements of the planning process, including, potentially, the application of net gain principles. Finally, a systematic baseline methodology and joined-up assessment process could further link to natural capital accounting and economic evaluation to support investment decisions.

As with any new approach, an iterative process, including significant engagement, is required to develop a robust and applicable method. This document represents an initial outline of the proposed methodology. It is expected to evolve, as lessons are learned from additional use of the framework in practice.

9 References

AECOM and ABPmer. (2018). *Marine Plan for Northern Ireland – Sustainability Appraisal. Volume 2: Sustainability Appraisal Report.* Report for the Northern Ireland Department for Agriculture, Environment and Rural Affairs

Atkins, J. P., Burdon, D., Elliott, M., & Gregory, A. J. (2011). Management of the marine environment: integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach. *Marine pollution bulletin*, *62*(2), 215-226.

Atkins. (2004) *Torridge district local plan sustainability appraisal. Final Report. February 2004.* Report produced by Atkins for Torridge District Council.

Ashley, M., Rees, S., Mullier, T., Reed, B., Cartwright, A., Holmes, L., Sheehan, E. (2020). *Isles of Scilly Natural Capital Asset and Risk Register to Inform Management of Isles of Scilly Fisheries Resources*. A report by research staff of the Marine Institute at the University of Plymouth

Ashley, M., Rees, S.E., and Cameron, A. (2018). *North Devon Marine Pioneer Part 1: State of the art report of the links between ecosystem and ecosystem services in the North Devon Marine Pioneer*. A report to WWF-UK by research staff the Marine Institute at Plymouth University

Barbier E.B. (1994). Valuing Environmental Functions: Tropical Wetlands: *Land Economics* 70(2): 155-173

Bateman I.J., Mace G.M., Fezzi C., Atkinson G. and Turner K. (2011). Economic Analysis for Ecosystem Service Assessments. *Environmental and Resource Economics, 48(2),* 177-218

Burdon, D., 2020. Review of marine cultural, social and heritage indicators. Report to Defra by Daryl Burdon Ltd., Willerby, UK (Report No. DB Ltd. 005/2019).

Burdon, D., Potts, T., Barbone, C., & Mander, L. (2017). The matrix revisited: A bird's-eye view of marine ecosystem service provision. *Marine Policy*, *77*, 78-89.

Burkhard, B.; Kandziora, M.; Hou, Y.; Muller, F. (2014.) Ecosystem service potentials, flows and demands – concepts for spatial localisation, indication and quantification. *Landscape Online 34:1-32*

Calne Town Council, Jones Lang LaSalle and Milward Oliver & Friends. 2012. *Calne Vision and Scoping Study.* http://www.calne.gov.uk/controls/DownloadDocument.ashx?docID=wu7676LIEQDZJRBMKQ1443mXvl&aID=1026 Accessed 20 September 2019

CEH. 2017. Land Cover Map 2015. Dataset documentation. Version 1.2, 22nd May 2017. Centre for Ecology and Hydrology. https://www.ceh.ac.uk/sites/default/files/LCM2015_Dataset_Documentation_22May2017.pdf Accessed 16 September 2019

Chan, K. M., Satterfield, T., & Goldstein, J. (2012). Rethinking ecosystem services to better address and navigate cultural values. *Ecological economics*, *74*, 8-18.

Collins, A.M., Coughlin, D., Miller, J., Kirk, S. 2015. *The Production of Quick Scoping Reviews and Rapid Evidence Assessments: A How to Guide.* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/560521/Production_of_quick_scoping_reviews_and_rapid_evidence_assessments.pdf Accessed 27 September 2019

Crosher, I., Gold, S., Heaver, M., Heydon, M., Moore, L., Panks, S., Scott, S., Stone, D., and White, N. (2019). *The Biodiversity Metric 2.0: Auditing and accounting for biodiversity value: technical supplement* (Beta version, July 2019). Natural England Joint Publication JP029. http://publications.naturalengland.org.uk/publication/5850908674228224 Accessed 26 September 2019

Culhane, F. E., Frid, C. L., Royo Gelabert, E., White, L., & Robinson, L. A. (2018). Linking marine ecosystems with the services they supply: what are the relevant service providing units? *Ecological Applications*, *28*(7), 1740-1751.

Daily G.C. (1997). Introduction. What are ecosystem services? In: Daily G.C. (Ed). *Nature's Services: Societal Dependence on Natural Ecosystems.* Island Press, Washington. 392pp

DECC. (2016). *UK Offshore Energy Strategic Environmental Assessment.* OESEA3 Environmental Report. Future Leasing/Licensing for Offshore Renewable Energy, Offshore Oil & Gas, Hydrocarbon Gas and Carbon Dioxide Storage and Associated Infrastructure. March 2016. Department for Energy and Climate Change.

Defra. (2020). *Enabling a Natural Capital Approach: Guidance.* January 2020. https://www.gov.uk/guidance/enabling-a-natural-capital-approach-enca#enca-guidance. Accessed 23 January 2020

Defra. (2019). *Net gain. Summary of responses and government response*. July 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/819823/net-gain-consult-sum-resp.pdf

Defra. (2018). *Measuring environmental change – draft indicators framework for the 25 Year Environment Plan Draft for discussion.* December 2018

Defra. (2007). *An introductory guide to valuing ecosystem services*. Published by the Department for Environment, Food and Rural Affairs. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69192/pb12852-eco-valuing-071205.pdf Accessed 28 September 2019

EEA. (2019). EUNIS marine habitat classification 2019. https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification/eunis-marine-habitat-classification-review-2019/eunis-marine-habitat-classification-2019/at_download/file. Accessed 19 July 2020.

eftec. (2009). *Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal.* Value Transfer Guidelines Submitted to Department for Environment, Food and Rural Affairs. December 2009.

eftec. (2015). *Environmental Value Look-up Tool*. Prepared for the Department for Environment, Food and Rural Affaris. http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19514. Accessed 28 September 2019

eftec & Environmental Futures Ltd. (2006). *Valuing Our Natural Environment* Final Report NR0103. For Department for Environment, Food and Rural Affairs. 20th March 2006

Erhard, M., Teller, A., Maes, J., Meiner, A., Berry, P., Smith, A. *et al.* (2016). *Mapping and assessment of ecosystems and their services. mapping and assessing the condition of Europe's ecosystems: Progress and challenges*. Luxembourg: Publications office of the European Union.

European Environment Agency. 2019. *EUNIS habitat classification*. https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification Accessed 16 September 2019

Firth, A. 2019. *Case Studies on the Dorset Stour and Tyne to Tees Marine Area*. Unpublished report for Historic England. Project Number HE 7751/7752; Fjodr Ref: 16440/16450. Tisbury: Fjodr Limited

Forum for the Future (undated). The Five Capitals https://www.forumforthefuture.org/the-five-capitals

FM3: Fairbank, Maslin, Maullin, Metz & Associates. (2010). Key findings from recent national opinion research on "ecosystem services". http://massland.org/files/TNC_Summary_Language_Memo.pdf

Geneletti, D. (Ed.). (2016). *Handbook on biodiversity and ecosystem services in impact assessment*. Edward Elgar Publishing.

Geneletti, D, A Bond, D Russel, J Turnpenny, W Sheate and A Jordan (2015), "Chapter 10: Ecosystem services and sustainability assessment: theory and practice", in A Morrison-Saunders, J Pope and A Bond (editors), *Handbook of Sustainability Assessment* (Edward Elgar, Cheltenham, UK and Northampton, USA) pages 215-234.

Haines-Young, R., & Potschin, M. B. (2018). *Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure. https://cices.eu/content/uploads/sites/8/2018/01/Guidance-V51-01012018.pdf*

Haines-Young, R., & Potschin, M. (2013). *Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August–December 2012. EEA Framework Contract No EEA/IEA/09/003.*: European Environment Agency.

Hattam, C., Atkins, J. P., Beaumont, N., Börger, T., Böhnke-Henrichs, A., Burdon, D. *et al.* (2015). Marine ecosystem services: linking indicators to their classification. *Ecological Indicators, 49*, 61–75.

Hattam, C., Hooper, T., & Papathanasopoulou, E. (2017). A well-being framework for impact evaluation: The case of the UK offshore wind industry. *Marine Policy*, *78*, 122-131.

Historic England. (2016). *Sustainability Appraisal and Strategic Environmental Assessment.* Historic England Advice Note 8.

HM Government. (2011a). *UK Marine Policy Statement*. March 2011. London: The Stationery Office

HM Government. (2011b). *The natural choice: securing the value of nature. HM Government Natural Environment White Paper. Presented to Parliament by the Secretary of State for Environment, Food and Rural Affairs by Command of Her Majesty*. https://www.gov.uk/government/publications/the-natural-choice-securing-the-value-of-nature

HM Government. (2018). *A green future: our 25 year plan to improve the environment*. London: Department for the Environment Food and Rural Affairs. https://www.gov.uk/government/publications/25-year-environment-plan

HM Treasury. (2018). *The Green Book. Central Government Guidance on Appraisal and Evaluation*. London.

Honrado, J.P., C. Vieira, C. Soares, M.B. Monteiro, B. Marcos, H.M. Pereira and M.R. Partidário (2013), *Can we infer about ecosystem services from EIA and SEA practice? A framework for analysis and examples from Portugal, Environmental Impact Assessment Review*, 40, 14–24.

Hooper, T. (2017). *Natural Capital and Local Decision Making*. Workshop Report. 20 November 2017.

Hooper, T., and Austen, M. 2020. *Application of the natural capital approach to Sustainability Appraisal*. *Method Summary*. August 2020. Report prepared as part of the South West Partnership for the Environment and Economic Prosperity (SWEEP) and the Marine Pioneer programme.

Hooper, T., Ashley, M., Börger, T., Langmead, O., Marcone, O., Rees, S., Rendon, O., Beaumont, N., Attrill, M. and Austen, M. (2019a). *Application of the natural capital approach to the marine environment to aid decision-making. Phase 1 Final Report.* Report prepared for the Department for Environment Food and Rural Affairs (project code ME5115).

Hooper, T., Ashley, M., Börger, T., Langmead, O., Marcone, O., Rees, S., Rendon, O., Beaumont, N., Attrill, M. and Austen, M. (2019b). *The Natural Capital Approach. What is it, and how does it fit into decision-making for coastal and marine areas?* Phase 1 Non-technical Summary prepared for the Department for Environment Food and Rural Affairs (project code ME5115).

Hooper, T., Ashley, M., Mullier, T. and Rees, S. (2020). *North Devon Marine Natural Capital Plan. Sustainability Assessment*. February 2020. Report prepared for the North Devon Biosphere Reserve as part of the South West Partnership for the Environment and Economic Prosperity (SWEEP) and the Marine Pioneer programme.

Hooper, T., Cooper, P., Hunt, A. and Austen, M. (2014). A methodology for the assessment of local-scale changes in marine environmental benefits and its application. *Ecosystem Services,* 8,65-74

JNCC. (2019). UK Biodiversity Indicators 2019. This document supports C2. Habitat Connectivity. Fiche. Last updated September 2019. UK BI2019 Fiche C2. http://data.jncc.gov.uk/data/6b221f34-dbe8-4fcc-9dfe-1cc8506fabeb/UKBI2019-F-C2.pdf. Accessed 20 July 2020.

JNCC. (2018). Marine habitat correlation tables: Spreadsheet version (v. 201801). https://hub.jncc.gov.uk/assets/62a16757-e0d1-4a29-a98e-948745804aec. Accessed 19 July 2020.

Karjalainen, T. P., Marttunen, M., Sarkki, S., & Rytkönen, A. M. (2013). Integrating ecosystem services into environmental impact assessment: an analytic–deliberative approach. *Environmental Impact Assessment Review*, *40*, 54-64.

La Notte, A., D'Amato, D., Mäkinen, H., Paracchini, M. L., Liquete, C., Egoh, B. *et al.* (2017). Ecosystem servicesclassification: A systems ecology perspective of the cascade framework. *Ecological Indicators, 74*, 392–402.

Lepus Consulting. 2019. *Sustainability Appraisal of the Chiltern and South Bucks Local Plan. Regulation 19 SA Report. Volume 2 of 2: Appendices*.

Lovett, A., Turner, K., Sünnenberg, G., Ferrini, S., Stephanou, E., & Greaves, S. (2018). *A natural capital asset check and risk register for the Anglian Water combined services area. Report to Anglian Water Services Ltd.*

Luck, G. W., Daily, G. C., & Ehrlich, P. R. (2003). Population diversity and ecosystem services. *Trends in Ecology & Evolution*, *18*(7), 331-336.

Lusardi, J., Rice, P., Waters, R.D., & Craven, J. (2018). Natural capital indicators: for defining and measuring change in natural capital. Natural England Research Report.

Jones, T. (2005). *Preliminary scoping report for the sustainability appraisal and strategic environmental assessment of the North Devon local development framework.* December 19 2005. Report prepared by Tom Jones, Independent Consultant for North Devon Council.

Mace, G. M., Hails, R. S., Cryle, P., Harlow, J., & Clarke, S. J. (2015). Towards a risk register for natural capital. *Journal of Applied Ecology, 52*, 641–653.

Mace, G. M., Bateman, I., Albon, S., Balmford, A., Brown, C., Church, A. *et al.* (2011). Chapter 2: Conceptual framework *UK National Ecosystem Assessment: Technical Report*. Cambridge: UNEP-WCMC.

Maes, J., Teller, A., Erhard, M., Grizzetti, B., Barredo, J. I., Paracchini, M. L. *et al.* (2018). *Mapping and assessment of ecosystems and their services: An analytical framework for ecosystem condition.* Luxembourg: Publications office of the European Union.

Maes, J., Teller, A., Erhard, M., Liquete, C., Braat, L., Berry, P. *et al.* (2013). *Mapping and assessment of ecosystems and their services. An analytical framework for ecosystem assessments under action 5 of the EU biodiversity strategy to 2020.* Luxembourg: Publications office of the European Union.

Maskell, L.C., Norton, L.R., Smart, S.M., Carey, P.D., Murphy, J., Chamberlain, P.M., Wood, C.M., Bunce, R.G.H. and Barr, C.J. 2008. Countryside Survey. CS Technical Report No.1/07 Field Mapping Handbook. Centre for Ecology and Hydrology. http://nora.nerc.ac.uk/id/eprint/5194/1/N005194CR.pdf Accessed 16 September 2019

MHCLG. (2019a). *National Planning Policy Framework*. Ministry of Housing, Communities and Local Government. February 2019.

MHCLG. (2019b) *Guidance: Strategic environmental assessment and Sustainability Appraisal*. First published 09 February 2015, last updated 22 July 2019 from the Ministry of Housing, Communities and Local Government https://www.gov.uk/guidance/strategic-environmental-assessment-and-sustainability-appraisal. Accessed 13 September 2019

Millennium Ecosystem Assessment. (2003). *Ecosystems and human well-being. A Framework for Assessment*. Washington D.C.: Island Press.

MMO. (2019a). *Marine Planning: Iteration 3 engagement for the north east, north west, south east and south west marine plan areas. Iteration 3: Public engagement on draft policies and supporting text for marine planning in the north east, north west, south east and south west*. https://www.gov.uk/government/publications/marine-planning-iteration-3-engagement-for-the-north-east-north-west-south-east-and-south-west-marine-plan-areas. Accessed 14 February 2019

MMO (2019b). *South West Inshore and Offshore Marine Plans Sustainability Appraisal Part 1: Introduction and Methodology.* Draft Report. A report produced for the Marine Management Organisation, MMO, September 2019, 45pp.

MMO. (2018). *South West Inshore and Offshore Marine Plan Areas Sustainability Appraisal Options Assessment Report*, 26th April 2018

MMO (2016a) *Marine Plan Areas Sustainability Appraisal. Sustainability Appraisal Scoping Report. Post Consultation.* A report produced for the Marine Management Organisation

MMO (2016b) S*ustainability Appraisal Report Cards*. Available at https://www.gov.uk/government/publications/sustainability-appraisal-scoping-report-north-east-north-west-south-east-south-west-marine-plans. Accessed 15 February 2019.

MMO. (2016c). *Sustainability Appraisal Scoping Report – Database July 2016.*https://www.gov.uk/government/publications/sustainability-appraisal-scoping-report-north-east-north-west-south-east-south-west-marine-plans Accessed 28 February 2019

MMO. (2014). *Marine Plan Areas in England*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/325688/marine_plan_areas.pdf. Accessed 19 July 2020

MOD. (2018). Sustainability and Environmental Appraisal Tools Handbook. Version 8.1 October 2018. Ministry of Defence.

Natural Capital Committee. (2020). *State of Natural Capital Annual Report 2020.*44pp. https://www.gov.uk/government/groups/natural-capital-committee

Natural Capital Committee. (2019a). *State of Natural Capital Annual Report 2019*. *Sixth report to the Economic Affairs Committee.*72pp. https://www.gov.uk/government/groups/natural-capital-committee

Natural Capital Committee. (2019b). *Natural Capital Terminology. August 2019*. https://www.gov.uk/government/groups/natural-capital-committee

Natural Capital Committee. (2017). *How to do it: a natural capital workbook*. 30pp. https://www.gov.uk/government/groups/natural-capital-committee

Natural Capital Committee. (2015). *The state of natural capital. protecting and improving natural capital for prosperity and well-being. Third report to the Economic Affairs Committee.* 73pp. https://www.gov.uk/government/publications/natural-capital-committees-third-state-of-natural-capital-report

Natural Capital Committee. (2014). *Towards a framework for defining and measuring changes in natural capital. Working Paper 1*. March 2014. https://www.gov.uk/government/publications/natural-capital-committee-initial-term-working-papers-2012-to-2015

Natural Capital Committee. (2013). *The State of Natural Capital: Towards a framework for defining and measuring changes in natural capital.* April 2013. https://www.gov.uk/government/publications/natural-capital-committee-initial-term-working-papers-2012-to-2015

Norris, K., Bailey, M., Keith, A., Maskell, L., Reading, C., Turner, S., ... & Watt, A. (2011). Biodiversity in the context of ecosystem services [chapter 4] in *The UK National Ecosystem Assessment: Technical Report*. Cambridge: UNEP-WCMC. http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx

North Devon UNESCO Biosphere Reserve. (2020). *North Devon Marine Natural Capital Plan* Draft for consultation March 2020.

https://www.northdevonbiosphere.org.uk/uploads/1/5/4/4/15448192/north_devon_marine_natural_capital_plan__draft_for_consultation_.pdf

ODPM (2004). *Sustainability Appraisal of Regional Spatial Strategies and Local Development Frameworks. Consultation Paper*. September 2004. Office of the Deputy Prime Minister. West Yorkshire: ODPM Publications

Pearce, D. (1988). Economics, equity and sustainable development. *Futures* 20(6) 598-605.

Populus J., Vasquez M., Albrecht J., Manca E., Agnesi S., Al Hamdani Z., Andersen J., Annunziatellis A., Bekkby T., Bruschi A., Doncheva V., Drakopoulou V., Duncan G., Inghilesi R., Kyriakidou C., Lalli F., Lillis H., Mo G., Muresan M., Salomidi M., Sakellariou D., Simboura M., Teaca A., Tezcan D., Todorova V. and Tunesi L. (2017). *EUSeaMap, a European broad-scale seabed habitat map*. 174p. http://doi.org/10.13155/49975

Potts, T., Burdon, D., Jackson, E., Atkins, J., Saunders, J., Hastings, E., & Langmead, O. (2014). Do marine protected areas deliver flows of ecosystem services to support human welfare? *Marine Policy*, *44*, 139-148.

Powys Council. 2017. *Powys Local Development Plan 2011-2026. Sustainability Appraisal Report. Composite Version Incorporating Matters Arising Changes. September 2017.* https://en.powys.gov.uk/article/4906/Sustainability-Appraisal-SA

Ramboll Environ Marine Planning Consultants and ClearLead Consulting Ltd. (2018). *South Marine Plan Areas. Final Sustainability Appraisal Report Part 1*. May 2018. Report prepared for the Marine Management Organisation

Rees, S.E., Ashley, M., Cameron, A. (2019). North Devon Marine Pioneer Report 2: A Natural Capital Asset and Risk Register A SWEEP/WWF-UK report by research staff the Marine Institute at Plymouth University

Rozas-Vásquez, D., Fürst, C., Geneletti, D., & Muñoz, F. (2017). Multi-actor involvement for integrating ecosystem services in strategic environmental assessment of spatial plans. *Environmental Impact Assessment Review*, *62*, 135-146.

RTPI. (2018). *Strategic Environmental Assessment. Improving the effectiveness and efficiency of SEA/SA for land use plans*. Royal Town Planning Institute. Practical Advice. January 2018

Shepard, C.C., Crain, C.M., and Beck, M.W. (2011) The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis. PLoS ONE 6(11): e27374.

Sunderland, T., Waters, R.D., Marsh, D. V. K., Hudson, C., and Lusardi, J. (2018). Accounting for National Nature Reserves: A natural capital account of the National Nature Reserves managed by Natural England. Natural England Research Report, Number 078. http://publications.naturalengland.org.uk/publication/4535403835293696

TEEB. (2010). *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. London: Earthscan.http://www.teebweb.org/our-publications/teeb-study-reports/ecological-and-economic-foundations/

Tillin, H.M., Langmead, O., Hodgson, B., Luff, A, Rees, S., Hooper, T. & Frost, M. 2019. Feasibility study for a Marine Natural Capital Asset Index for Scotland. *Scottish Natural Heritage Research Report No. 1071.*

Torres, C., and Hanley, N. (2017). Communicating research on the economic valuation of coastal and marine ecosystem services. *Marine Policy*, 75, 99-107.

Torridge District Council and North Devon Council. (2018). *North Devon and Torridge Local Plan 2011-2031* Adopted October 2018 v1 31 October 2018.

Torridge District Council and North Devon Council. (2016a). *North Devon and Torridge Local Plan. Publication Draft Sustainability Appraisal.* May 2016.

Torridge District Council and North Devon Council. (2016b). *North Devon and Torridge Local Plan. Publication Draft – Main Changes. Sustainability Appraisal – Technical Document C. SA/SEA Full Appraisal Tables.* May 2016.

Torridge District Council and North Devon Council. (2016c). *North Devon and Torridge Local Plan. Publication Draft – Main Changes. Sustainability Appraisal – Technical Document E. North Devon Sites Appraisal*. May 2016.

Turpie J.K. (2003). The existence value of biodiversity in South Africa: how interest, experience, knowledge, income and perceived level of threat influence local willingness to pay. *Ecological Economics* 46: 199-216

UK Habitat Classification Working Group (2018). The *UK Habitat Classification.* http://ecountability.co.uk/ukhabworkinggroup-ukhab

UK National Ecosystem Assessment. (2011). *The UK National Ecosystem Assessment: Technical Report*. Cambridge: UNEP-WCMC. http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx

UK National Ecosystem Assessment. (2014). *The UK National Ecosystem Assessment Follow On: Synthesis of Key Findings*. Cambridge: UNEP-WCMC. http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx

United States Environmental Protection Agency. (2015). *National Ecosystem Services Classification System (NESCS): Framework Design and Policy Application. EPA-800-R-15-002.* . Washington DC: United States Environmental Protection Agency.

Watkinson, A. (2017). Scotland's Natural Capital Asset Index. Detailed model (data to 2017). https://www.nature.scot/scotlands-natural-capital-asset-index-detailed-model-data-2017 Accessed 22 September 2019.

Wigley, S., Paling, N., Rice, P., Lord, A., and Lusardi, J. (2020) National Natural Capital Atlas, Natural England Commissioned Report Number 285.

Wood Environment & Infrastructure Solutions UK Limited. (2019). *Sustainability Appraisal of the Doncaster Local Plan 2015 - 2035: Publication Version Sustainability Appraisal including Non-Technical Summary.* August 2019

APPENDIX 1: Evaluating Compatibility with Statutory Requirements

A1.1 Background

Between September 2018 and March 2019, the possibility of applying a natural capital approach to the 'live' Sustainability Appraisal for the South West Marine Plan was explored. This is being developed by the Marine Management Organisation (MMO) as part of their statutory obligations under the Marine and Coastal Access Act 2009. The MMO is responsible for Marine Plans for all English waters, and are developing these on a regional basis, with inshore and offshore plans for each region (Figure A1). The East and South Marine Plans have both been adopted, and the Marine Plans for the other regions are currently being prepared.

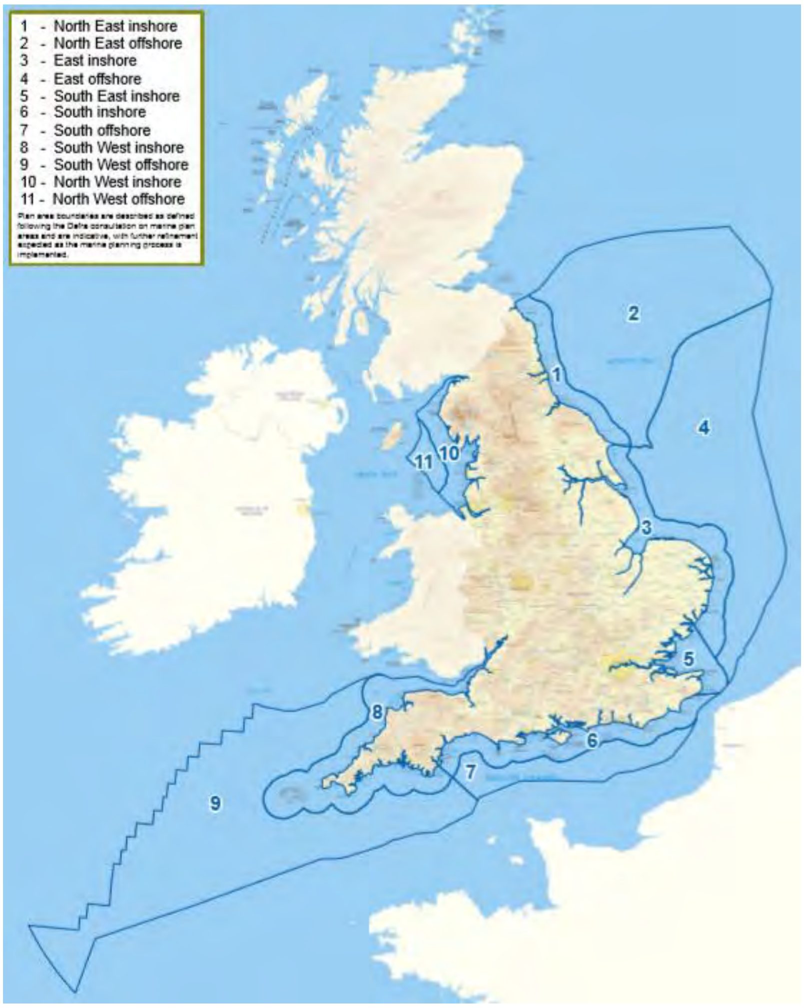


Figure A1. The English Marine Plan Areas (MMO, 2014)

The Sustainability Appraisal process for the South West Marine Plan was already underway before the opportunity for using a natural capital approach was considered. Therefore, the application of a new approach in this context incorporates the work already undertaken and ongoing. It builds from the point of the completed Sustainability Appraisal scoping assessment (MMO, 2016a,b,c; 2018) and takes account of the drafts of other marine plan documents, which at the time were in Iteration 3 (MMO, 2019a). The opportunities within this case study were also constrained by the 'live' nature of the marine planning process, which (being a statutory obligation) has defined, rigidly timetabled stages and requires interaction with parties operating under specific contracts with the MMO. However, it did provide the opportunity to determine whether a natural capital approach was compatible with the statutory requirements for Sustainability Appraisal and to explore a preliminary framework for the collation of baseline information.

A1.2 Key elements of the Sustainability Appraisal scoping process

The mandatory requirements for Sustainability Appraisal include consideration of "*biodiversity, population, human health, fauna, flora, soil, water, air, climatic factors, material assets, cultural heritage including architectural and archaeological heritage, landscape*", as listed in Annex I of the SEA Directive (and Schedule 2 of the Environmental Assessment of Plans and Programmes Regulations 2004). The Marine Policy Statement provides a similar list of environmental considerations, as well as a more detailed list of the key activities that should be considered when appraising economic and social implications (Table A1). In practice in the marine context, Sustainability Appraisal and SEA use these lists, often almost verbatim, to define a series of topics around which the assessment will be framed (Table A2).

Table A1. The environmental, economic and social considerations of which account must be taken marine planning, as required in the Marine Policy Statement (HM Government, 2011a)

Environmental considerations	Economic and social considerations
Marine ecology and biodiversity	Marine Protected Areas
Air quality	Defence and security
Noise	Energy production and infrastructure development
Ecological and chemical water quality and resources	Ports and shipping
Seascape	Marine aggregates
Historic Environment	Marine dredging and disposal
Climate Change Adaptation and mitigation	Telecommunications cabling
Coastal Change and Flooding	Fisheries
	Aquaculture
	Surface water management and wastewater treatment and disposal
	Tourism and recreation

Table A2. A comparison of the environmental elements listed within Annex I of the SEA Directive with two examples of topics chosen to frame an Offshore Energy SEA (DECC, 2016) and the Sustainability Appraisal for a marine plan for Northern Ireland (AECOM and ABPmer, 2018)

SEA Annex I	Offshore Energy SEA (DECC, 2016)	Northern Ireland marine plan sustainability appraisal (AECOM and ABPmer, 2018)
Biodiversity Fauna Flora	Biodiversity, habitats, flora and fauna; Conservation of sites and species	Biodiversity, flora and fauna
Population Human health	Population and human health	Socio-demographics
Soil Water	Geology, substrates, coastal geomorphology Water environment	Water and soils
Air	Air quality	Air quality
Climatic factors	Climate and meteorology	Climatic factors
Material assets	Other users and material assets	Material assets; Uses and activities
Cultural heritage	Cultural heritage	Cultural heritage
Landscape	Landscape/seascape	Landscape and seascape

The scoping process for the South West Marine Plan Sustainability Appraisal (MMO, 2016a,b,c; 2018) was similarly framed around a standard series of topics and subtopics (Table A3). Extensive work was undertaken to create a substantial database (MMO, 2016c) which allocated unique topic identifiers to multiple policies, targets, baselines, issues and data gaps relevant to the different subtopics, and linked through to the sources of supporting evidence. An excerpt from this database is shown in Figure A2. Subsequently, this database was used during the process of screening and identifying significant effects of the different options through which the marine plan could seek to achieve the UK's Higher Level Marine Objectives (MMO, 2018). A series of groupings (themes) was identified, each of which had several possible options (Table A4). A further database (MMO, unpublished data) was created, which used a traffic light system to summarise the likely impact of each option within each grouping for each of the relevant individual topics and sub-topics, linking back to the relevant topic identifier and underlying evidence (Figure A3). The scoping process also included extensive narrative reporting (MMO, 2016a; 2018) and summaries in the form of report cards (MMO, 2016b).

Table A3. The topics and sub-topics used to frame the South West Marine Plan areas Sustainability Appraisal scoping process (MMO 2016a, 2016b, 2018)

Topic Area	Sub-Topic
Air	Air pollutants
Biodiversity	Benthic and Inter-Tidal Ecology Fish and Shellfish (including cephalopods) Invasive Species Marine Mega Fauna (including marine mammals and turtles) Ornithology Plankton Protected Sites and Species
Climate	Climate change resilience and adaptation (including coastal flooding) Greenhouse gas emissions
Communities	Effects on communities (including employment and skills) Effects on protected equality groups Health and wider determinants of health
Cultural	Heritage Assets adjacent to Marine Plan Areas Heritage Assets within Marine Plan Areas
Economy	Aggregate Extraction Defence Dredging and disposal Energy Generation and infrastructure development - Carbon capture and storage Energy Generation and infrastructure development - Conventional Energy Energy Generation and infrastructure development - Fossil Fuels Energy Generation and infrastructure development - Nuclear Energy Generation and infrastructure development – Renewables Fisheries and aquaculture Leisure / recreation Marine manufacturing Ports and shipping Seabed Assets (including cables, outfalls and pipelines) Tourism
Geology	Coastal features and processes Seabed substrates and bathymetry
Landscape	Landscape designations and landscape and seascape character.
Water	Marine litter Pollution and water quality (including eutrophication) Tides and currents Water temperature and salinity

Topic Idenfier	SA Topic Area	Sub-Topic	Description of Policy/Target, Baseline, Issue or Data Gap	Policy/Target/ Baseline/Issue/Gap
Air_1	Air	Air pollutants	The Marine Policy Statement for the UK recognises that activities and developments in the marine and coastal area can have adverse effects on air quality	Policy / Target
Air_2	Air	Air pollutants	The MARPOL Convention aims to prevent marine pollution from ships and in part from oil rigs and production platforms. Six annexes covering pollution by oil, noxious liquids carried in bulk, harmful substances in packaged form, sewage, garbage and air pollution. MARPOL (Marine Pollution Convention, 1973 / 1978) is the main international convention governing the prevention of pollution of the marine environment from ships and in part oil rigs and production platforms. It covers pollution by chemicals, oil, harmful substances in packaged form, rubbish, sewage and air pollution. It was amended in 2008 to further reduce harmful emissions from ships of sulphur oxides (SOx) and nitrogen oxides (NOx). There are also regulatory controls on atmospheric emissions for oil and gas platforms e.g. EU Emissions Trading System and Pollution Prevention and Control Regulations	Policy / Target
Air_3	Air	Air pollutants	Relevant annexes of the Ospar Convention include I: Prevention and elimination of pollution from land-based sources (point or diffuse sources) / II: Prevention and elimination of pollution by dumping or incineration (vessels, aircrafts or offshore installations) and III: Prevention and elimination of pollution from offshore sources.	Policy / Target
Air_4	Air	Air pollutants	Article 222 (UNCLOS), defines enforcement with respect to pollution from or through the atmosphere	Policy / Target
Air_5	Air	Air pollutants	Directive 1996/62/EC aims to ensure prevention and reduction of airborne pollutants for the protection of human health and tl	Policy / Target
Air_6	Air	Air pollutants	Strategic Framework for Air Quality Objectives for key air pollutants: controls and monitors the levels of airborne pollutants. Marine licensing should meet the general aim of a reduction in the amount of airborne pollutants that are produced.	Policy / Target

Figure A2. An extract from the marine plan areas Sustainability Appraisal scoping report database (MMO, 2016c)

Table A4. The different groupings that reflect the key issues within the South West Marine Plan area, and the number of options within each considered by the Sustainability Appraisal scoping process (MMO, 2018)

Grouping	Number of options	Grouping	Number of options
Access	9	Habitat Loss	13
Aquaculture	9	Heritage Assets	15
Cables	7	Infrastructure	9
Climate change	14	Litter	6
Coastal change	11	MPAs and Geodiversity	14
Co-existence	13	Non Native Invasive Species	6
Disturbance	10	Ports and Harbours	7
Dredge Disposal	7	Recreation	11
Dredge Harbours and Ports	4	Renewables	6
Deep Sea Habitat	8	Seascape	7
Ecosystem Approach	6	Shipping	6
Employment: Diversification	4	Species	12
Employment: Growth Skills	11	Tourism	7
Energy	5	Water Quality	10
Fisheries	7		

SA Topic	SA Sub Topic	Policy Option A		Policy Option B		Policy Option C	
		Significance	SA Database Topic Identifier	Significance	SA Database Topic Identifier	Significance	SA Database Topic Identifier
Cultural heritage	Heritage Assets within marine plan areas	Uncertain (Lack of Evidence)	Cultural_184	Uncertain (Dependent on Implementation)	Cultural_167	Not Significant	
	Heritage Assets adjacent to marine plan areas	Significant Negative	Cultural_178, Economy_767	Uncertain (Dependent on Implementation)	Cultural_178, Economy_767	Not Significant	
Biodiversity, Habitats, Flora and Fauna	Protected sites and species	Significant Negative	Biodiv_474	Uncertain (Dependent on Implementation)	Biodiv_474	Not Significant	
	Benthic and inter-tidal ecology Fish and shellfish	Significant Negative	Biodiv_470, Biodiv_471, Biodiv_476, Biodiv_487	Uncertain (Dependent on Implementation)	Biodiv_470, Biodiv_471, Biodiv_476, Biodiv_487	Not Significant	Biodiv_470, Biodiv_471, Biodiv_476, Biodiv_487
	Marine mega fauna	Uncertain (Lack of Evidence)	Biodiv_467, Biodiv_468, Biodiv_469, Biodiv_650	Uncertain (Dependent on Implementation)	Biodiv_467, Biodiv_468, Biodiv_469, Biodiv_650	Not Significant	Biodiv_467, Biodiv_468, Biodiv_469, Biodiv_650

Figure A3. An extract from the marine plan areas Sustainability Appraisal scoping report database (MMO, unpublished data)

A1.3 Applying the natural capital framework

The existence of the scoping databases (with their systematic layout) was of fundamental importance in facilitating reclassification of the information into the natural capital framework. In the first step of this process, the information for each topic identifier that had been labelled as relevant to all Marine Plan areas or to the South West Marine Plan area was extracted. This information was used to allocate each topic identifier to at least one of the elements and subtypes from the natural capital framework, as listed in Figure 6 (of the main report). A spreadsheet was compiled with the complete natural capital classification for each row within the MMO (2016c) Sustainability Appraisal scoping report database (for the data applicable to the South West Marine Plan). This spreadsheet adds 16 columns to the original database (Table A4). Not all of these columns are necessarily completed for each topic identifier, although this format provides for the systematic recording of how the topic interacts with the multiple elements of the natural capital framework (e.g. which services link to specific assets, the impacts of particular activities on particular assets, or the legislation governing a specific asset or the benefits derived from it). Thus, the conceptual natural capital classification (Figure 6) was expanded with a 'detail' column unique to the South West Marine Plan case study, reflecting the additional relevant factors related to the issues considered (Table A5).

Table A4. The additional information added to the MMO (2016c) scoping database to provide the natural capital classification for each topic identifier

Column header	Description	Options
Natural capital element	The high-level natural capital category, from the conceptual framework.	Asset (bioic), Asset (abiotic), Service, Disservice, Other capital, Benefit, Impact, Governance
SPU type	The Service Providing Unit (SPU): i.e. the broad category of asset (biotic or abiotic) from which services are derived[1]	Benthos, Mobile species, Air, Water Column, Substrate
Habitat detail	The specific habitat type.	Unrestricted[2]
Species	The species of interest.	Unrestricted[2]
Service Class	The broad ecosystem service category, from standard ecosystem service classifications.	Provisioning, Provisioning (Carrier)[3], Regulating, Cultural
Service subclass	A more detailed hierarchy of the ecosystem service type.	Unrestricted[2,4]
Disservice type	The broad category of naturally occurring species or process that may cause harm to the economy or society.	Invasive species, Harmful/Toxic species
Benefit type	The broad sector to which benefits accrue	Economic, Security, Health, Wellbeing
Benefit detail	Additional characteristics of the benefit	Unrestricted[2]
Impact origin	Whether the impact occurs locally to the area of scope of governance, or is external to it	Local, External
Impact source/type	Further details of the source of the impact (such as specific activities or climate change)	Unrestricted[2]
Governance type	Major elements of the governance system that constrain, inform or otherwise affect aspects of resource use and management.	Designations, Consents and Licensing, Legislation, Management Plans, Processes
Governance detail	Details or the relevant governance issue such as specific designations, legislation or agencies involved	Unrestricted[2]
Other capital type	The broad capital category, from the five capitals concept[5]	Financial, Human, Manufactured, Social
Other capital detail	Additional information about the other types of capital.	Unrestricted[2]
Additional summary detail	Key additional details from the wider topic description, such as the nature of impacts (e.g. noise, entanglement) or the specifics of governance processes.	Unrestricted[6]

[1] See e.g. Luck et al. (2003) and Culhane et al. (2018) for further explanation of the SPU concept.
[2] See Table A5 for the categories derived for the South West Marine Plan context.
[3] This subcategory of non-extractive use refers to the role of the sea in providing space for e.g. transport (see Hooper et al., 2014).
[4] A classification system such as CICES (Haines-Young and Potschin, 2018) could be applied.
[5] See e.g. Forum for the Future (undated) for further explanation of the five capitals concept
[6] In some cases (such as the nature of impacts) these have the potential to be refined into systematic categories.

Table A5. Natural capital elements, sub-types and details derived from the South West Marine Plan scoping process

Element	Sub-type	Detail
Asset (biotic)	Benthos	Intertidal
		Subtidal
		Deep sea
		Beaches
		Coastal Lagoons
		Mudflat
		Saltmarsh
		Sand dunes
		Echinoderms
		Molluscs
		Sand dwelling species
		Shellfish
		Protected sites
	Mobile species	Basking sharks
		Cetaceans
		Fish
		Marine mammals
		Marine megafauna
		Plankton
		Seabirds
		Seals
		Turtles
		Waterbirds
		Protected species
Asset (abiotic)	Air	
	Water column	
	Substrate	
Service	Provisioning	Aggregates
		Energy
		Food
		Seaweed
	Provisioning (carrier)	Military activity
	Regulating	Climate regulation
	Cultural	Leisure and recreation
		Environmental interaction
		Visual amenity
Disservice	Invasive species	Pacific oysters
		American drill oyster
		Leathery sea squirt
		Other/unspecified
	Harmful/toxic species	Plankton/algae
Other capital	Manufactured capital	Heritage assets
		Ports, harbours
		Infrastructure
		Cables
	Human capital	Jobs
		Skills
Benefit	Economic	Income/revenue
		Employment
		Market goods
		Development
		Reduced expenditure
	Security	Energy security
		Food security
	Health	Physical health
		Mental health
	Wellbeing	
Impact	Local origin	Aggregate and mineral extraction
		Agriculture
		Aquaculture
		Cables, pipelines
		Coastal defence, erosion, development
		Commercial fisheries
		Defence, national security
		Dredging
		Hazardous substances
		Historic sources
		Industry, other activities
		Marine litter, pollution, noise
		Ports, harbours, shipping
		Recreation, tourism
		Renewables, other energy
	External origin	Marine litter
		Climate change
Governance	Designations	Marine Conservation Zone
		Heritage Coast
		Ramsar site
		Site of Special Scientific Interest
		Special Protection Area
		Blue Flag status
	Consents, licensing	Oil and gas
		Offshore wind farms
		Dredge disposal
		Historic environment
	Legislation	Bathing Water Directive
		Marine Strategy Framework Directive
		Marine Strategy Regulations 2010
		Water Framework Directive
	Management Plans	River Basin Management Plan
		Shoreline Management Plan
	Processes	

Figure A4 shows how the components of the original scoping framework map onto the proposed natural capital approach. This is not intended as a classification tool, but to illustrate how the information as organised within the scoping topics applies to multiple natural capital categories. An example of how the scoping report database (MMO, unpublished data) would look when the information is presented in the natural capital framework is given in Figure A5.

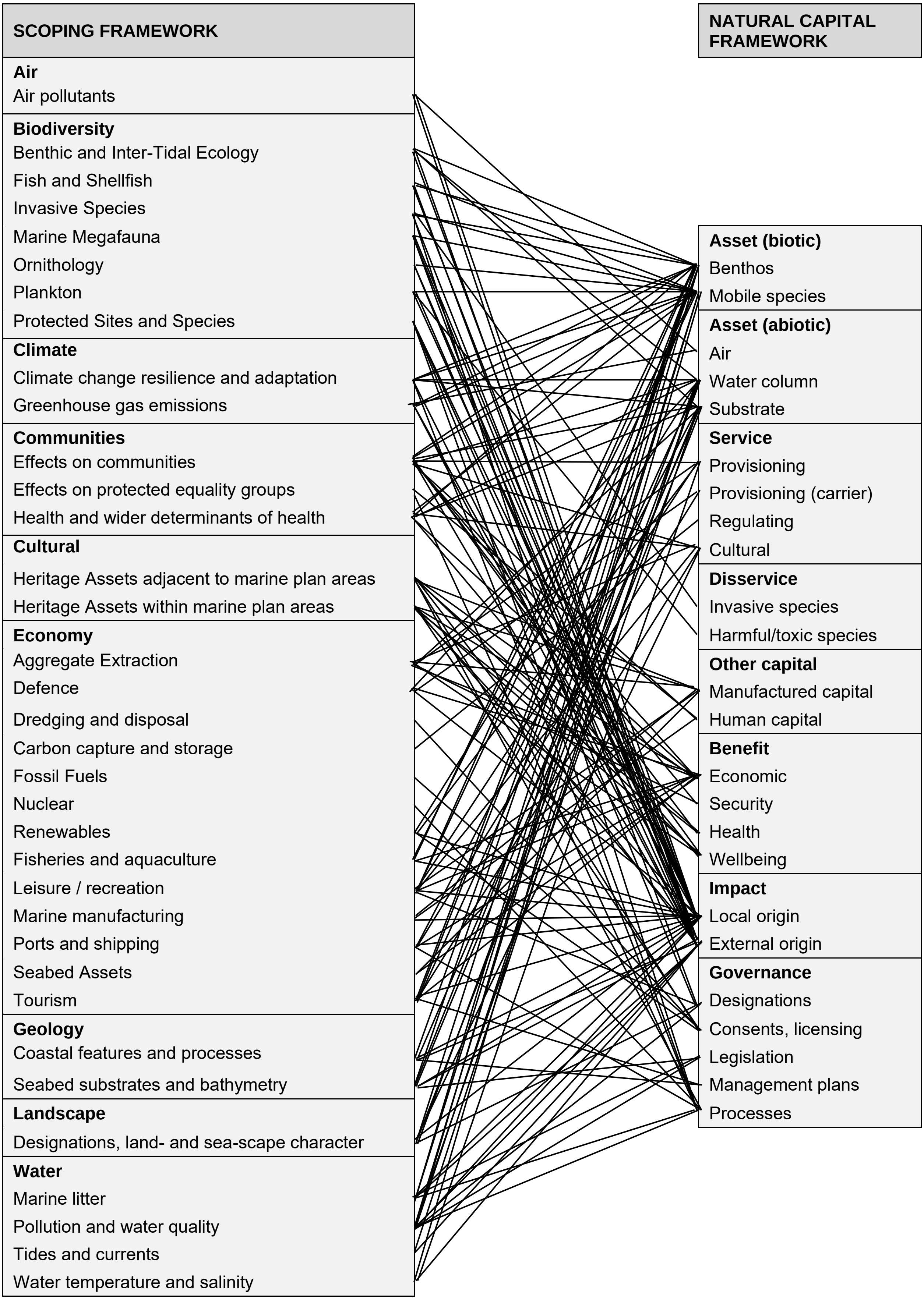


Figure A4. Mapping topics and sub-topics from the South West Marine Plan scoping process onto the natural capital framework

Natural Capital Element	Natural Capital Detail	Policy Option A		Policy Option B		Policy Option C	
		Significance	SA Database Topic Identifier	Significance	SA Database Topic Identifier	Significance	SA Database Topic Identifier
Asset (biotic)	Benthic habitat	Uncertain (Lack of Evidence)	Biodiv_574	Not Significant	Biodiv_574	Not Significant	Biodiv_574
	Basking sharks, marine mammals, seals	[illegible]	Biodiv_502, Biodiv_503, Biodiv_649, Biodiv_536, Biodiv_537, Biodiv_538, Biodiv_546, Biodiv_547, Biodiv_554, Biodiv_555, Biodiv_556	Uncertain (Dependent on Implementation)	Biodiv_502, Biodiv_503, Biodiv_649, Biodiv_536, Biodiv_537, Biodiv_538, Biodiv_546, Biodiv_547, Biodiv_554, Biodiv_555, Biodiv_556	Uncertain (Lack of Evidence)	Biodiv_502, Biodiv_503, Biodiv_649, Biodiv_536, Biodiv_537, Biodiv_538, Biodiv_546, Biodiv_547, Biodiv_554, Biodiv_555, Biodiv_556
	Waterbirds, seabirds	[illegible]	Biodiv_465, Biodiv_274	Uncertain (Dependent on Implementation)	Biodiv_465, Biodiv_274	Uncertain (Lack of Evidence)	Biodiv_465, Biodiv_274
Asset (abiotic)	Air	Uncertain (Dependent on Implementation)	Air_19, Air_23	[illegible]	Air_19, Air_23	Uncertain (Dependent on Implementation)	Air_19, Air_23
Service	Visual amenity	Uncertain (Dependent on Implementation)	Landscape_132 Landscape_133	Uncertain (Dependent on Implementation)	Landscape_132 Landscape_133	Not Significant	Landscape_132 Landscape_133
	Leisure and recreation	Uncertain (Lack of Evidence)	Water_271	Not Significant	Water_271	Uncertain (Lack of Evidence)	Water_271
		Uncertain (Dependent on Implementation)	Economy_631	Uncertain (Dependent on Implementation)	Economy_631	Not Significant	Economy_631

Figure A5. An extract from the South West Marine Plan scoping report database (MMO, unpublished data) presented using the natural capital framework

A1.4 Conclusion

Consideration of the information collated during the scoping phase of the Sustainability Appraisal for the South West Marine Plan has shown that it is relatively straightforward to map the original scoping topic areas onto a natural capital framework, and in doing so ensure that the legislative requirements are met. However, the process of undertaking the Sustainability Appraisal for the South West Marine Plan was already underway before the opportunity for using a natural capital approach as considered. As a result, there are some restrictions on what could be proposed. Applying a natural capital approach from the very beginning of a Sustainability Appraisal process would provide additional options. In particular, the scoping phase could be framed around the development of asset and risk registers. As with the proposed reframing of the main phase described above, this would not change the type of information that should be collected, as Sustainability Appraisal scoping has the same objective as the development of asset and risk registers; to understand what is there, what state it is in, and what the current threats to it are. The use of asset and risk registers provides the opportunity to formalise the process and present the outcomes systematically and in line with Government policy aspirations for natural capital based decision making. A comprehensive, systematic process for baseline assessment would also help to ensure that all aspects of natural capital and ecosystem services were considered. The South West Marine Plan example shows that there are some possible gaps in the scoping around regulating services.

Ultimately, a natural capital approach to Sustainability Appraisal was not adopted for the marine plans: *"MMO have explored the inclusion of natural capital through the SA process. MMO have discussed with academia, lead experts in government and the SA consultancy team as to what could be possible at this stage of the SA and in the future. As Marine natural capital is still in its infancy, it was ultimately deemed too early to incorporate a robust natural capital approach into the SA. At the time of the SA being undertaken, no clear definition of what the natural capital approach is for the marine area exists. It is therefore unfeasible to define and implement any methodology within the sustainability appraisal process. Once a definition and agreed approach is confirmed at a national level, it may be possible to include natural capital in a marine plan SA."* (MMO, 2019b).

APPENDIX 2: Case Study - North Devon Marine Natural Capital Plan

PML | Plymouth Marine Laboratory

UNIVERSITY OF PLYMOUTH Marine Institute

North Devon Marine Natural Capital Plan
Sustainability Assessment


© Miles Wolstenholme


© Nilfanion


© Dickelbers


© Kate Weld

CONSULTATION DRAFT
February 2020

sweep

Suggested citation
Hooper, T., Ashley, M., Mullier, T. and Rees, S. 2020. *North Devon Marine Natural Capital Plan. Sustainability Assessment*. February 2020. Report prepared for the North Devon Biosphere Reserve as part of the South West Partnership for the Environment and Economic Prosperity (SWEEP) and the Marine Pioneer programme.

Contact
Tara Hooper
Plymouth Marine Laboratory
Prospect Place
The Hoe
Plymouth
Devon
PL1 3DH

Acknowledgements
This work was funded by the Natural Environment Research Council through the South West Partnership for the Environment and Economic Prosperity (SWEEP; grant NE/P011217/1). The authors are also very grateful to the North Devon Marine Pioneer teams.

Picture credits

1 Summary

The purpose of this assessment is to consider how the Marine Natural Capital Plan (MNCP) could impact upon the marine environment, coastal communities, and maritime economy in North Devon. The MNCP is the first iteration of what is expected to be an evolving process, and serves to build the necessary framework for long term sustainable management. Thus, few detailed benchmarks are included in the sustainability assessment, which instead evaluates the expected direction of travel of the MNCP. The sustainability appraisal uses a natural capital framework in order to continue to test the approach being developed under the SWEEP programme and the Marine Pioneer.

Several plans and policies interact with the MNCP, most of which have similar high-level objectives to: support sustainable development of the maritime economy; protect the marine environment; connect people to nature; and develop strong and just societies. These include the South West Marine Plan, the North Devon and Torridge Local Plan, fisheries byelaws from the Inshore Fisheries and Conservation Authorities, national conservation legislation relating to the protection of landscapes, habitats and species, and the 25 Year Environment Plan.

Thirty sustainability objectives are defined, which overlap significantly with the objectives of the MNCP itself as a result of the overarching aims of the MNCP being intrinsically linked to sustainable development. The sustainability objectives encompass natural, human, social, manufactured and financial capital, and include those for species populations, habitats, heritage; engagement of fishers, recreational users and the wider public; strengthening networks; minimising the impact of new infrastructure; and securing inward investment. Indicators for each objective are given within the sustainability assessment framework. Few policy targets exist at present (and mostly concern water quality and protected areas), but more targets are expected to be defined as the MNCP evolves.

The baseline assessment includes (i) an asset register, (ii) an ecosystem services inventory, and (iii) a risk register. It highlights the large extent of subtidal sedimentary habitats, the presence of estuarine mussel beds, saltmarsh and mudflats, and the important sand dunes. Wetland and sea bird populations are found in the Taw Torridge and on Lundy, demersal fish species as well as crab and European lobster are important for commercial fisheries, and protected species include seals, porpoise, spiny lobster and pink sea fans. Heritage assets range from scheduled ancient monuments and protected wreck sites to memorials to sailors and fishermen. The North Devon marine area also provides important ecosystem services (and associated benefits), particularly related to tourism, recreation and leisure, seascape and cultural heritage, and commercial fisheries. Marine and coastal habitats (especially saltmarsh) also contribute to regulating and maintenance services including carbon sequestration, water quality, coastal defence, and the provision of nursery habitats for fishery species. The continued supply of ecosystem services and benefits from the assets of the North Devon marine area is in some cases at risk however, due to the level of pressure on certain habitats. The ability of subtidal habitats to support food production, and saltmarsh condition are of most concern.

The sustainability assessment compares implementing the plan versus not doing so. In the short term (1-5 years), the principal positive impacts relate to human, social and financial capital, due to the expected strengthening of networks, improved governance, data-sharing, raising awareness, and new finance initiatives. Impacts on natural capital assets, ecosystem services and benefits are largely neutral. In the longer term, positive impacts are expected for sudtidal habitats where management measures reduce sea bed abrasion and for local stocks that have limited exposure to external pressures. Water quality is expected to improve as the MNCP supports actions to reduce diffuse pollution, and improved water quality is likely to increase the economic viability of mussel harvesting. There is potential for positive impact on cultivated seafood and macro-algae as well as tidal energy if the MNCP intention to support maritime industries is realised through the establishment of new businesses. A reduction in litter is likely to improve aesthetic quality, with improvements potentially occurring quickly with increasing support for ongoing initiatives. The quality of nursery habitats may increase if management reduces subtidal abrasion impacts, and through increasing saltmarsh area. More saltmarsh will also increase climate regulation, although benefits may be relatively limited, depending on the extent to which current land use promotes carbon uptake. Impacts on recreation are expected to be neutral, although there may be a decline in benefits from bait digging. It is not possible to make useful judgments about the likely effects on erosion control and flood protection. The limited benefits of the MNCP reflect the limitations of local management: ensuring positive outcomes for natural capital is also dependent on national and international governance.

2 Introduction

2.1 Background and Scope

The purpose of this assessment is to consider how the Marine Natural Capital Plan (MNCP) could impact upon the marine environment, coastal communities, and maritime economy in North Devon. The MNCP broadly follows the North Devon Marine Pioneer boundary (Figure 1) but extends seaward to 20nm and includes part of Bridgwater Bay. The MNCP reaches to the tidal limits of the Taw and Torridge rivers, and also includes the area up to 1km inland for the purposes of accounting for economic flows, thus joining to the boundary of the North Devon Landscape Pioneer. The governance and actions of the plan (and hence the scope of the sustainability assessment) are restricted to the marine component of the North Devon Biosphere.

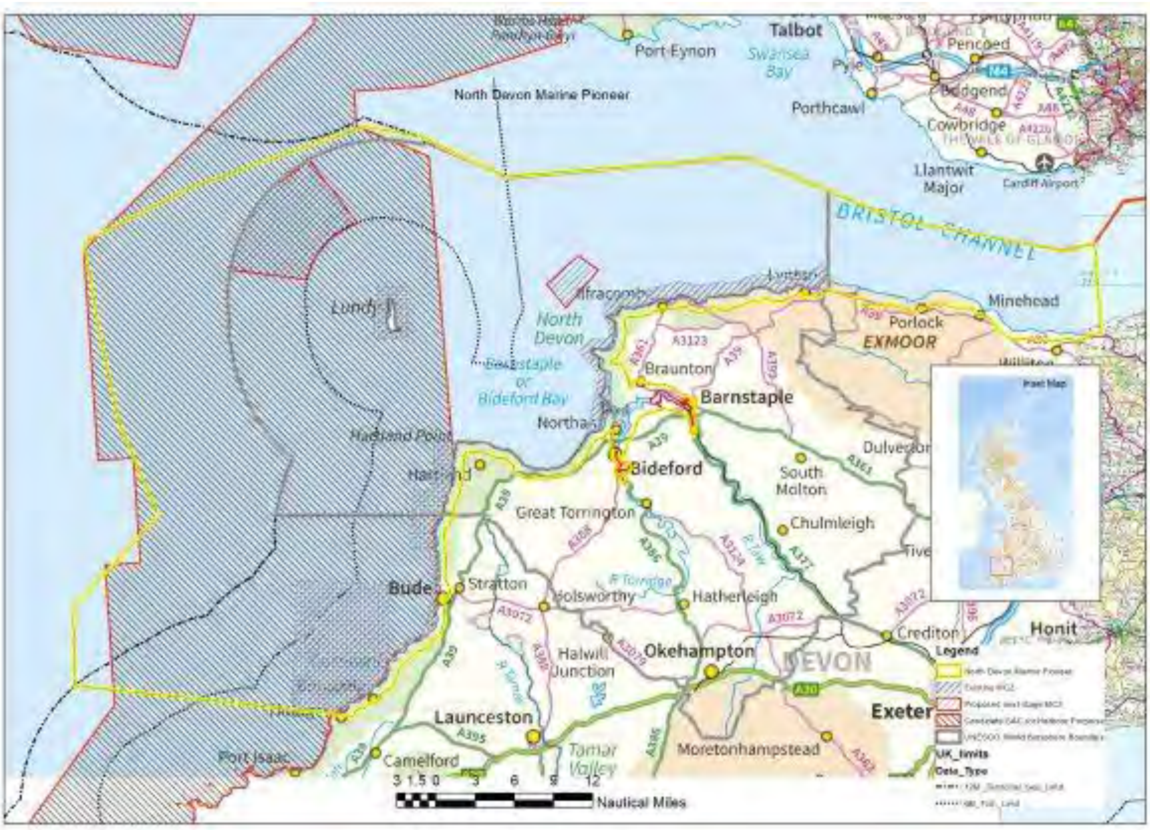


Figure 1. The area covered by the North Devon Marine Natural Capital Plan.

The MNCP is the first of its kind in the UK, and is the first iteration of what is expected to be an evolving process. This initial plan therefore primarily serves to build the necessary framework for long term sustainable management: to put in place a participatory governance structure, and to initiate or support the development of further management plans, financing options, research programmes and data sharing that address specific issues and sectors. Thus, few detailed benchmarks are included in the sustainability assessment, which instead evaluates the expected direction of travel of the MNCP. Future iterations, into which learning from, and specific actions developing as a result of, this first phase will be incorporated, are expected to include more specific targets for species, habitats and maritime sectors.

The sustainability appraisal is structured using a natural capital framework in order to continue to test, and enabling further refinement of, the approach being developed under the SWEEP programme and the Marine Pioneer (Hooper et al., 2019).

2.2 Relevant plans and policies

The principal plans and policies that interact with the MNCP include, at the regional level, the South West Marine Plan (SWMP; MMO, 2020a), which is currently in draft form as it progresses through public consultation. The SWMP has 13 specific objectives within three high level objectives from the Marine Policy Statement (HM Government, 2011): (1) achieving a sustainable marine economy; (2) ensuring a strong, healthy and just society; and (3) living within environmental limits. The SWMP also contains a number of specific policies that support delivery of the objectives. These policies are wide ranging, and concern different sectors and locations. The key text of those with particular relevance to the MNCP are summarised in Table 1.

Table 1. Extracts from the main policies within the South West Marine Plan (MMO, 2020a) of relevance to the North Devon Marine Natural Capital Plan.

Policy code	Policy text
SW-AQ-2	Proposals enabling the provision of infrastructure for sustainable aquaculture and related industries will be supported.
SW-REN-1	Proposals that enable the provision of renewable energy technologies and associated supply chains, will be supported.
SW-WIND-1	Proposals for offshore wind inside areas of identified potential will be supported.
SW-HER-1	Proposals that demonstrate they will conserve and enhance elements contributing to the significance of heritage assets will be supported.
SW-FISH-1	Proposals supporting a sustainable fishing industry, including the industry's diversification, should be supported.
SW-FISH-3	Proposals enhancing essential fish habitat, including spawning, nursery and feeding grounds, and migratory routes should be supported.
SW-EMP-1	Proposals that result in a net increase to marine related employment will be supported
SW-CC-1	Proposals which enhance habitats that provide flood defence or carbon sequestration will be supported.
SW-ML-1	Public authorities must make adequate provision for the prevention, re-use, recycling and disposal of waste to reduce and prevent marine litter. Public authorities should aspire to undertake measures to remove marine litter within their jurisdiction.
SW-WQ-1	Proposals that enhance and restore water quality will be supported.
SW-SOC-1	Those bringing forward proposals are encouraged to consider and enhance public knowledge, understanding, appreciation and enjoyment of the marine environment as part of (the design of) the proposal.
SW-MPA-1	Proposals that support the objectives of marine protected areas and the ecological coherence of the marine protected area network will be supported.
SW-BIO-1	Proposals that enhance the distribution of priority habitats and priority species will be supported.
SW-BIO-3	Proposals that deliver environmental net gain for coastal habitats where important in their own right and/or for ecosystem functioning and provision of ecosystem services will be supported.
SW-NG-1	Proposals should deliver environmental net gain for marine or coastal natural capital assets and services.

At a more local level, the North Devon and Torridge Local Plan (Torridge District Council and North Devon Council, 2018) has four strategic aims:

Aim 1: A Vibrant Northern Devon Economy – where excellent opportunities support diverse low carbon growth and moves towards an economy that supports our world class environment.

Aim 2: A World Class Environment – where important assets are valued and enhanced for future generations.

Aim 3: A Balanced Local Housing Market – where a choice of decent housing of all types is available and new development meets community needs.

Aim 4: Mixed Communities – where there is a strong community spirit and the opportunity for an excellent quality of life.

A number of the general Local Plan objectives (such as diversifying the local economy without adverse environmental and social impacts, learning and skills development, habitat protection, and improving public access to the environment to support wellbeing) apply to marine and coastal areas, but the plan also includes objectives that make explicit reference to marine and maritime issues:

- sustainable growth in the maritime, engineering, tourism and leisure economies;
- the undeveloped coastline, estuarine and important countryside assets of northern Devon are protected and enhanced;
- development improves water quality in rivers, lakes, estuary and coastal waters to help deliver the South West River Basin Management Plan objectives

The Local Plan also includes a Coast and Estuary Strategy (Policy ST09), elements of which concern maintaining and enhancing the cultural heritage and landscape setting of coastal communities; a diverse maritime economy; defence against coastal erosion and tidal flooding; and improving water quality, as well as stressing the importance of the coastal, estuarine and marine environments. The Devon and Severn Inshore Fisheries and Conservation Authority (IFCA) are responsible for legislation and enforcement specific to fisheries (both wild capture and mariculture), which includes byelaws related to permitting for mobile fishing, potting, netting and diving for scallop, crab and lobster, and the management of shellfish beds. The IFCA are also developing Fisheries Research and Management Plans. Voluntary agreements are also in place for ray and whelk fisheries (Ashley et al., 2018).

Also pertinent to the MNCP is national conservation legislation relating to the protection of landscapes, habitats and species associated within the designated Sites of Special Scientific Interest (SSSIs), Marine Conservations Zones (MCZs), Area of Outstanding Natural Beauty (AONBs), and Special Areas of Conservation (SACs) within the marine and coastal areas of the North Devon Biosphere Reserve. These highlight the important species, habitats and other features that require protection. The MNCP interacts with the North Devon AONB, four SACs (Braunton Burrows, Lundy, Bristol Channel Approaches and Tintagel-Marsland-Clovelly Coast), five MCZs (Lundy, Northwest of Lundy, Morte Platform, Bideford to Foreland Point, Hartland Point to Tintagel, and the South West Approaches) and more than 20 SSSIs in coastal areas, including the Taw-Torridge estuary, Exmoor coast, Saunton to Baggy Point, and Northam Burrows. Salmon and Sea trout are also subject to national management objectives (Cefas, Evironment Agency & Natural Resources Wales, 2018).

Defra’s 25 Year Environment Plan (25YEP; HM Government, 2018) sets out the vision for national environmental policy. It seeks to secure clean, healthy productive and biologically diverse seas and oceans through implementing a sustainable fisheries policy, and achieving good environmental status while allowing marine industries to thrive and completing an ecologically coherent network of well-management marine protected areas. The 25YEP also contains commitments to reduce marine litter and reduce risks from flooding and coastal erosion as well as having wider objectives (not linked explicitly to the marine environment but of relevance to it), to recover nature and enhance the beauty of landscapes; connect people with their environment; and reduce pollution.

3 Sustainability Objectives

The overarching aims of the MNCP focus on ensuring environmental improvement, empowering communities, and securing coastal livelihoods, and thus are intrinsically linked to sustainable development. Therefore, there is significant overlap with the sustainability objectives and those of the MNCP itself. A similar approach was taken for the South West Marine Plan (MMO, 2019), for which the sustainability appraisal does not have separate objectives, but instead considers the wider objectives of the Marine Plan and associated policies. The five capitals model (Forum for the Future, undated; Table 2) was used in formulating the sustainability objectives, to ensure that they had relevance across different aspects of the environment, society and the economy. The full list of sustainability objectives is given in Table 3.

Table 2. Descriptions for each of the five capitals (Hooper et al., 2019).

Capital type	Description
Natural	Encompasses natural resources as well as the processes needed to sustain life and produce goods and services.
Social	Networks together with shared norms, values and understandings that facilitate cooperation within or among groups (such as families, unions, schools, voluntary organisations)
Human	The health, knowledge, skills and capabilities of individuals.
Manufactured	Goods or assets that contribute to the production process or the provision of services, rather than being part of the output itself. It includes, for example tools, machinery, buildings and infrastructure.
Financial	Those assets of an organisation that exist in a form of currency that can be owned or traded, including shares, bonds and banknotes.

Table 3. The sustainability objectives for the North Devon Marine Natural Capital Plan

Natural Capital (including related heritage)

- Disturbance of waterbirds, sea birds and marine mammals is reduced
- All mussel beds in the Taw Torridge estuary rated at least Class B by 2030
- All designated bathing waters reach guideline standards by 2025
- All estuarine and coastal water bodies reach appropriate standards under the Water Framework Directive
- Commercial stocks of fish and shellfish (wild capture) increase
- Stocks of salmon and sea trout are maintained above their conservation limits
- Health of fish habitats is maintained and where possible improved
- Disturbance of intertidal mudflats in the Taw Torridge estuary from recreational bait collection (bait digging, crab tiling) is reduced
- The quantity of plastic waste and litter on beaches and in the water column is reduced
- Carbon storage capacity of the Taw Torridge estuary is increased
- Disturbance (scour) of subtidal sediments is reduced
- Levels of protection for environmental assets are maintained and where possible improved
- Environmental quality in protected areas reaches at least minimum acceptable status
- Likely relative condition of subtidal habitats is maintained and where possible improved
- The cultural heritage value of ongoing inshore fisheries is maintained

Human Capital

- Employment opportunities increase in mariculture, shellfish hand-harvesting, and value-added activities for wild capture fisheries, where these do not exceed levels of sustainable exploitation
- The availability of data on (and therefore knowledge of) environmental, social and economic issues related to marine areas is increased
- Local people are motivated to take part in environmental initiatives
- Members of the public are motivated to improve their behaviour around waste disposal
- Recreational users are motivated to improve their behaviour in order to minimise environmental disturbance
- Fishers and harvesters are more engaged in sustainable fisheries management

Social Capital

- Networks for sustainable management of coastal and marine areas are strengthened
- Recreational users are more engaged with sustainable management
- Conflict amongst marine users is reduced
- The use of citizen science data in decision making is increased

Manufactured Capital

- New infrastructure for renewable energy and mariculture conforms to sustainability criteria
- New mooring infrastructure is installed to reduce habitat damage due to anchoring and scour from traditional moorings

Financial Capital

- Incomes for fishers/harvesters using low-impact techniques are maintained, and where appropriate increased, through sustainable management of resources and value-added activities
- The economic contribution of recreation and tourism linked to marine and coastal natural capital is maintained
- New financial mechanisms and products are established to support maritime activities and environmental protection

4 Baseline

Extensive, detailed information on North Devon's marine area, including on species, habitats, and activities such as fisheries, recreation and tourism has already been collated and analysed by Ashley et al. (2018) and Rees et al. (2019), much of which is available through the geodatabase (https://pioneer-geonode.plymouth.ac.uk), and so will not be duplicated here. This assessment will instead provide a short narrative summary taken, with the exception of the information on heritage assets, primarily from Ashley et al. (2018) and Rees et al. (2018), with additional information from Hooper (2013). This is accompanied by a series of summary tables comprising: (i) an asset register (with both species and habitats), (ii) an ecosystem services inventory, and (iii) a risk register.

In terms of natural capital assets, the marine area is dominated by sedimentary habitats, particularly sand and coarse sediments. There are also rocky reef areas, and pockets of macro-algae. Intertidal habitats include mussel beds, saltmarsh and mudflats within the Taw Torridge estuary, as well as rocky shores and sandy beaches. The sand dunes at Braunton and Northam Burrows are important coastal margin habitats and support protected species including the petalwort and sandbowl snail. The estuary supports some regionally and nationally important populations of waterbirds, and curlew, lapwing and golden plover are designated features of protected areas. Protected seabirds including puffins, razorbill, Manx shearwater, guillemot and kittiwake are found in the area, primarily on the cliffs of Lundy. Subtidally, demersal fish species as well as crab and European lobster are important for commercial fisheries, and protected species include seals, porpoise, spiny lobster and pink sea fans.

The evaluation of heritage assets was beyond the scope of Ashley et al. (2018) and Rees et al. (2019), but they were described by Hooper (2013), whose work was informed particularly by Preece (2005, 2008). The estuary contains two scheduled ancient monuments (a buried Bronze Age stone row at Isley Marsh, and the Bideford Long Bridge), as well as three prehistoric sites at Westward Ho! The remains of several fish weirs can be found in the Taw, and assets related to shipbuilding remain on the banks of the Torridge. Historic military infrastructure can be found at Instow and, particularly, on Braunton and Northam Burrows. Further heritage assets are recorded on local lists maintained by local authorities (North Devon Council, undated; Torridge District Council, undated). These include memorials to sailors and fishermen, buildings associated with the former uses of Fremington Quay and with Victorian/Edwardian seaside tourism in Ilfracombe and Woolacombe, a former lifeboat station, and riverfront warehouses. Historic England (undated) lists two wrecks designated under the Protection of Wrecks Act 1973, both close to Lundy: the Iona II, an American paddlesteamer lost in 1864, and the remains of a 15th/16th Century ship wrecked at Gull Rock.

Tourism, recreation and leisure are extremely important in North Devon, with watersports participation making a significant economic contribution. The seascape and cultural heritage of the area are also important services that contribute to its popularity as a visitor destination. Ray, whelk, lobster and sole contributed over 80% of the value of annual landings into North Devon ports in 2018 (MMO, 2020b). There are also moderate levels of hand-harvesting of mussels from beds within the estuary, a commercial operator culturing oysters in Porlock, and occasional harvesting of purple laver and cockles from rocky shores. Bait collection (particularly for rag- and lugworm, and tiling for moulting shore crabs) occurs frequently on mudflats in the estuary. Spat for seeding mussel beds elsewhere has previously been collected, but is not occurring at the present time. The estuary is also used for commercial shipping into Appledore and Bideford and for military exercises, particularly amphibious craft training. A tidal energy test site can be found at Lynmouth, although is currently dormant. Marine and coastal habitats (especially saltmarsh) also contribute to regulating and maintenance services including carbon sequestration, water quality (through filtration, remediation and other processing of waste and toxins), coastal defence, and the provision of nursery habitats for fishery species. The continued supply of ecosystem services and benefits from the assets of the North Devon marine area is in some cases at risk however, due to the level of pressure on certain habitats. The ability of subtidal habitats to support food production and the condition of saltmarsh are of most concern.
The following tables summarise data on the key habitats, species and ecosystem services in the North Devon marine area. Their extent (quantity), trends in that extent, and condition are summarised,

and some monetary values for benefits from ecosystem services are provided. Quantified information is given where available for extent and value, while trends and condition are categorised. The information in Tables 4–7 is primarily from Rees et al. (2019) and Ashley et al. (2018), with further information from Hooper (2013), and additional fisheries landing values from MMO (2020). Rees et al. (2019) and Ashley et al. (2018) also include confidence assessments and caveats related to the data. For example, the data on which fisheries stock assessments are based is collected on a much larger spatial scale and the sampling methods used are not the most appropriate for some of the species documented. The method for development of the risk register and the justification for the risk scoring are also given in Rees et al. (2019).

4.1 Asset register summary

Table 4. The extent and condition of the major habitats in the North Devon marine area

Key:

	Positive	Stable	Negative	
Trend				
Condition	Good	Acceptable	Of concern	Insufficient data

Broad Habitat	Detail (with EUNIS code)	Extent (km^2)	Extent trend	Condition
Sparsely vegetated land				
Supralittoral sediment	Sand dune	6.72		
	Sand dune with shrubs	0.39		
	Shingle	0.17		
Marine inlets and transitional waters				
Littoral rock	Littoral rock and other hard substrata (A1)	11.31		
	High energy littoral rock (A1.1)	5.73		
	Moderate energy littoral rock (A1.2)	2.98		
	Low energy littoral rock (A1.3)	1.69		
	Features of littoral rock (A1.4)	0.38		
	Littoral chalk communities (B3.114, B3.115, A1.441, A1.2143)	0.002		
	Honeycomb worm, Sabellaria alveolata reef (A2.71, A2.711, A5.612)	0.004		
	Intertidal underboulder communities (A1.2142, A3.2112)	0.03		
	Estuarine rocky habitats	1.18		
	Supralittoral rock (lichen or splash zone) (B3.1)	0.85		
Littoral sediment	Littoral sediment (A2)	29.31		
	Littoral coarse sediment (A2.1)	0.76		
	Littoral sand and muddy sand (A2.2)	14.99		
	Littoral mixed sediments (A2.4)	0.45		
	Littoral biogenic reefs (A2.7)	0.01		
	Features of littoral sediment (A2.8)	0.03		
	Coastal saltmarshes and saline reedbeds (A2.5)	2.80		
	Blue mussel beds	0.28		
	Littoral mud (A2.3)	9.98		
Sublittoral habitats				
Sublittoral rock	Infralittoral rock and other hard substrata (A3)	17.27		
	Atlantic and Mediterranean high energy infralittoral rock (A3.1)	11.19		
	Atlantic and Mediterranean moderate energy infralittoral rock (A3.2)	2.12		
	Atlantic and Mediterranean low energy infralittoral rock (A3.3)	0.07		
	Features of infralittoral rock (A3.7)	0.0003		
	Circalittoral rock and other hard substrata (A4)	876		
	Atlantic and Mediterranean high energy circalittoral rock (A4.1)	477		
	Atlantic and Mediterranean moderate energy circalittoral rock (A4.2)	394		
	Fragile sponge & anthozoan communities on subtidal rocky habitats			
Sublittoral sediment	Sublittoral coarse sediment (A5.1)	2,845		
	Sublittoral sand (A5.2)	1,690		
	Sublittoral mud (A5.3)	10.85		
	Sublittoral mixed sediments (A5.4)	48.56		
Sublittoral vegetated habitats	Tide-swept algal communities (L.hyperborea) (A3.126, A3.213)	0.68		
	Kelp and seaweed communities on sublittoral sediment (A5.52)			
Transitional and shelf waters	Shelf waters	5,500		
	Estuarine waters	2.45		

Table 5. The extent and condition of key species (designated as protected features or particularly important for ecosystem services) in the North Devon marine area

Key:

	Positive	Stable	Negative	
Trend	Positive	Stable	Negative	Insufficient data
Condition	Good	Acceptable	Of concern	Insufficient data

Scientific name	Common name	Quantity	Quantity unit	Quantity trend	Condition
Uria aalge	Guillemot	6,198	Census count	Positive	Good
Rissa tridactyla	Kittiwake	238	Apparently occupied nests	Positive	Of concern
Puffinus puffinus	Manx shearwater	3,451	Pairs	Positive	Good
Fratercula arctica	Puffin	375	Census count	Positive	Good
Alca torda	Razorbill	1,735	Census count	Positive	Good
Numenius arquata	Curlew	623	Annual peak count	Negative	Acceptable
Pluvialis apricaria	Golden Plover	3,184	Annual peak count	Negative	Good
Vanellus vanellus	Lapwing	2,765	Annual peak count	Negative	Acceptable
Branta canadensis	Canada Goose	597	Annual peak count	Insufficient data	Insufficient data
Anas penelope	Wigeon	391	Annual peak count	Negative	Insufficient data
Anas crecca	Teal	290	Annual peak count	Positive	Insufficient data
Anas platyrhynchos	Mallard	236	Annual peak count	Negative	Insufficient data
	Waterbird assemblage			Negative	Acceptable
Gadus morhua	Cod	0	n per km²	Negative	Acceptable
Pleuronectes platessa	Plaice	2,698	n per km²	Stable	Acceptable
Solea solea	Sole	4,437	n per km²	Stable	Acceptable
Clupea harengus	Herring	0	n per km²	Stable	Acceptable
Raja clavata	Thornback ray	444	n per km²	Stable	Acceptable
Raja microocellata	Small eyed ray	67	n per km²	Stable	Of concern
Raja brachyura	Blonde ray	200	n per km²	Stable	Of concern
Dicentrarchus labrax	Bass	22	n per km²	Stable	Insufficient data
Loligo vulgaris/forbesii	Squid	469	n per km²	Positive	Insufficient data
Salmo salmar	Salmon	1	n per license day	Negative	Acceptable
Salmo trutta	Sea trout	1	n per license day	Stable	Acceptable
Cancer pagurus	Crab	Insufficient data		Insufficient data	Acceptable
Homarus gammarus	Lobster	Insufficient data		Insufficient data	Acceptable
Petalophyllum ralfsii	Petalwort	Insufficient data		Insufficient data	Acceptable
Palinurus elephas	Spiny lobster	Insufficient data		Insufficient data	Of concern
Eunicella verrucosa	Pink sea-fan	Insufficient data		Insufficient data	Good
Catinella arenaria	Sandbowl Snail	Insufficient data		Insufficient data	Insufficient data
Buccinum undatum	Common whelk	Insufficient data		Insufficient data	Insufficient data
Halichoerus grypus	Grey seal	Insufficient data		Insufficient data	Good
Phocoena phocoena	Harbour porpoise	278-1713	individuals	Insufficient data	Good

5 *Ecosystem Services*

Table 6. An inventory of the main ecosystem services provided by the North Devon marine area

Key: *Trend* — Positive (green); Stable (amber); Negative (red); Insufficient data (grey)

Category	Services/benefits delivered	Quantity	Trend	Value
Food: Cultivated seafood	Oysters	Low	Insufficient data	
Foraged plants	Purple laver (*Porphyra*)	Low	Insufficient data	
Game and wild fish (commercial harvesting)	Cod	2.82 t/yr	Negative	£13,206
	Plaice	3.37 t/yr	Negative	£5,728
	Sole	4.75 t/yr	Negative	£111,799
	Herring	0.17 t/yr	Stable	£441
	Thornback ray	71.07 t/yr	Negative	
	Small eyed ray	7.25 t/yr	Negative	£480,906
	Blonde ray	93.02 t/yr	Negative	
	Crab	16.18 t/yr	Negative	£95,107
	Lobster	14.61 t/yr	Negative	£285,213
	Whelk	117.97 t/yr	Stable	£400,226
	Squid	0.05 t/yr	Negative	£39,376
	Bass	2.46 t/yr	Negative	£20,058
	Other marine species	222 t		£128,324
	Mussels	Moderate	Insufficient data	
	Cockles/whelk	Low	Insufficient data	
Materials: Non-food products	Bait	High	Insufficient data	
Genetic resources	Mussel spat	Inactive	Insufficient data	
Energy: Energy from non-living sources	Tidal energy testing	Inactive	Insufficient data	
Carrier: Commercial and other transport	Commercial shipping	Low	Insufficient data	
Military training/operations	Amphibious craft training	Moderate	Insufficient data	
Environmental quality: Water quality	Bioremediation, filtration, dilution	4,607km^{2}*	Stable	
Maintaining wild populations:	Nursery habitat	3,400km^{2}*	Stable	
Hazard and nuisance reduction: Erosion control Flood protection	Sea defence	47km^{2}*	Stable	
Pest and disease control			Insufficient data	
Climate regulation	Carbon sequestered	7,572 t/yr	Stable	£168,689
Physical, experiential, intellectual interactions:				
Recreation, tourism, other experiential opportunities	Watersports participation#	34,070 people	Insufficient data	£28million
Scientific and educational opportunities		Moderate	Insufficient data	
Cultural significance of nature: Aesthetic		High	Insufficient data	
Heritage, spiritual and representational significance		High	Insufficient data	
Non-use values			Insufficient data	

* Area of habitat providing moderate or significant contribution to the service
\# By local residents. Includes swimming and angling

5.1 Risk register summary

Table 7. The risk to the continued delivery of ecosystem services (ES) by key assets in the North Devon marine area (reproduced from Rees et al., 2019)

For each ES the top row is risk assessed in relation to analysis of indicator data in relation to policy targets, the lower row for each ES is risk assessed in relation to (local) community based knowledge of risk.
Risk register confidence assessment in relation to robustness and agreement of evidence (confidence was assessed for status and trend and therefore confidence is sum of both)

		Agreement	
		High	Low
Robustness	*Significant evidence*	1	3
	Limited evidence	2	4

	High confidence	Low confidence
Low risk	*A*	*A*
High (or unknown) risk	*B*	*B-C*
Very high risk	*C*	*C*

Ecosystem Service Benefits / Assets

	Saltmarsh			Littoral rock			Littoral coarse sediments			Littoral sand and muddy sand			Littoral mud		
Risk category policy	Qun	Qal	Sp.	Qun	Qal	Sp.	Qun	Qal	Sp.	Qun	Qal	Sp.	Qun	Qal	Sp.
Risk cat. Community	Risk: Local community			Risk: Local community			Risk: Local community			Risk: Local community			Risk: Local community		
Food (Wild Food - fish and shellfish).			*												
Food - local															
Healthy climate (carbon sequestration).			*												
Climate -local															
Sea defence. (natural hazard regulation / flood prevention).			*												
Sea defence - local															
Recreation and Tourism			*												
Recreation and Tourism - local															
Clean water and sediments.			*												
Clean water -local															

	Littoral mixed sediments			Littoral biogenic reefs			Infralittoral rock			Circalittoral rock			Sublittoral coarse sediment		
Risk category policy	Qun	Qal	Sp.	Qun	Qal	Sp.	Qun	Qal	Sp.	Qun	Qal	Sp.	Qun	Qal	Sp.
Risk cat. Community	Risk: Local community			Risk: Local community			Risk: Local community			Risk: Local community			Risk: Local community		
Food (Wild Food - fish and shellfish).			*			*	*	*				*			*
Food - local															
Healthy climate (carbon sequestration).						*	*	*							
Climate -local															
Sea defence. (natural hazard regulation / flood prevention).			*			*	*	*							
Sea defence - local															
Recreation and Tourism							*	*				*			
Recreation and Tourism - local															
Clean water and sediments.						*									*
Clean water -local															

	Sublittoral sand			Sublittoral mud			Sublittoral mixed sediments			Water bodies			Bathing waters		
Risk category policy	Qun	Qal	Sp.	Qun	Qal	Sp.	Qun	Qal	Sp.	Qun	Qal	Sp.	Qun	Qal	Sp.
Risk cat. Community	Risk: Local community			Risk: Local community			Risk: Local community			Risk: Local community			Risk: Local community		
Food (Wild Food - fish and shellfish).			*			*			*				*	*	
Food - local															
Healthy climate (carbon sequestration).															
Climate -local															
Sea defence. (natural hazard regulation / flood prevention).															
Sea defence - local															
Recreation and Tourism													*	*	
Recreation and Tourism - local															
Clean water and sediments.			*			*			*				*	*	
Clean water -local															

	Shellfish waters			Fish (quota species)			Fish (non-quota species)			Fish (migratory species (salmon and sea trout)		
Risk category policy	Qun	Qal	Sp.	Qun	Qal	Sp.	Qun	Qal	Sp.	Qun	Qal	Sp.
Risk cat. Community	Risk: Local community			Risk: Local community			Risk: Local community			Risk: Local community		
Food (Wild Food - fish and shellfish).				*	*		*	Lob, (Med-ium risk) Crab, (Low risk)		*		*
Food - local												
Healthy climate (carbon sequestration).												
Climate -local												
Sea defence. (natural hazard regulation / flood prevention).												
Sea defence - local												
Recreation and Tourism				*	*		*	Lob, (Med-ium) Crab, (Low)		*		*
Recreation and Tourism - local												
Clean water and sediments.												
Clean water -local												

6 Sustainability Assessment Framework

6.1 Objectives and indicators

The sustainability assessment framework, with indicators, objectives and the sources of data for the indicators is presented in Table 8 (see following page). Indicators are suggested for each objective, but it is not always the case that the relevant data is currently available (either it is not yet collected at all, not at an appropriate resolution, or not publicly available). However, these indicators have been included as it is anticipated that data gathering and information sharing will be strengthened under the MNCP, allowing these indicators to be monitored in the future.

6.2 Targets

Policy targets relevant to the sustainability assessment are listed in Table 9. Although currently there are few, more targets are likely to be defined as actions within the MNCP (such as the development of fisheries management plans) progress.

Table 9. Policy targets relevant to the sustainability assessment objectives and indicators.

Objective	Indicator	Target	Source
All mussel beds in the Taw Torridge estuary rated at least Class B by 2030	Annual rating of shellfish water quality	Harmful plankton and reported toxin levels are below action levels	Water Framework Directive
All designated bathing waters reach guideline standards by 2025	Annual rating of bathing water quality	Number of designated bathing waters maintained or increased. All bathing waters are at least 'sufficient'	Bathing Waters Directive
All estuarine and coastal water bodies reach appropriate standards under the Water Framework Directive	Annual water body status rating	All water bodies achieve 'good' or 'high' status	Water Framework Directive
Stocks of salmon and sea trout are maintained above their conservation limits	Stock status category	Conservation limits are met or exceeded in at least four out of five years	Cefas, Environment Agency and Natural Resources Wales, 2017
Levels of protection for environmental assets are maintained and where possible improved	Percentage area within designated and voluntary marine protected areas	10% of habitats are within marine protected areas	CBD, 2010
Environmental quality in protected areas reaches at least minimum acceptable status	Condition assessment in protected area monitoring reports	At least 95% of habitats within marine protected areas has the conservation objective 'maintain' or is in 'favourable' condition	Natural England, 2017

Table 8. The sustainability objectives and indicators, including the expected sources of data for monitoring the indicators, and the likely availability of those data.

Objectives	Indicators	Data source and availability*	
Natural Capital (including heritage)			
Disturbance of waterbirds, sea birds and marine mammals is reduced	Number of disturbance incidents (from disturbance surveys)	NDBR[1]	C
All mussel beds in the Taw Torridge estuary rated at least Class B by 2030	Annual rating of shellfish water quality	CEFAS[2]	A
All designated bathing waters reach guideline standards by 2025	Annual rating of bathing water quality	Environment Agency	A
All estuarine and coastal water bodies reach appropriate standards under the Water Framework Directive	Annual water body status rating	Environment Agency	A
Commercial stocks of fish and shellfish (wild capture) are within safe biological limits, and where possible are increased	(i) Stock sizes for, particularly, herring, bass, whelk, squid, skates and rays; (ii) Extent of Taw Torridge mussel beds; (iii) Size structure of Taw Torridge mussel beds	(i) CEFAS, IFCA[3] (ii) IFCA (III) IFCA	B B B
Stocks of salmon and sea trout are maintained above their conservation limits	(i) Catch per unit effort (from stock surveys) (ii) Stock status category	CEFAS, Environment Agency	A
Health of fish habitats is maintained and where possible improved	Extent and condition of spawning and nursery habitats	CEFAS	B
Disturbance of intertidal mudflats in the Taw Torridge estuary from recreational bait collection (bait digging, crab tiling) is reduced	Size of disturbed area (from aerial photography)	IFCA, NDBR	C
The quantity of plastic waste and litter on beaches is reduced	Quantity of litter removed from beaches	MCS[4]	B A
Carbon storage capacity of the Taw Torridge estuary is increased	Extent/condition of saltmarsh (from aerial photography/LiDAR)	NDBR	B
Disturbance (scour) of subtidal sediments is reduced	(i) Frequency of anchoring within restricted zones (from aerial photography) (ii) Area of scoured seabed around moorings (from surveys)	NDBR	C
Levels of protection for environmental assets are maintained and where possible improved	(i) Percentage area within designated and voluntary marine protected areas; (ii) Percentage area protected by management measures;	Natural England, IFCA	A
Environmental quality in protected areas reaches at least minimum acceptable status	Condition assessment in protected area monitoring reports	Natural England	A
Likely relative condition of subtidal habitats is maintained and where possible improved	Intensity of fishing and other activities (e.g. aggregate extraction) that impact on the seabed	IFCA, MMO[5]	B
The cultural heritage value of ongoing inshore fisheries is maintained	Number of licenced inshore fishing vessels	MMO, IFCA	A

* Baseline data for the indicators, where available, has already been compiled within the asset and risk register (see Rees et al., 2019 and Ashley et al., 2018)

Data key: A = Appropriate data currently available; B = Some available data but may be issues with e.g. access to it or spatial resolution; C = Data not yet available

Acronyms: 1 = North Devon Biosphere Reserve; 2 = Centre for the Environment, Fisheries and Aquaculture Science; 3 = Inshore Fisheries and Conservation Authority; 4 = Marine Conservation Society; 5 = Marine Management Organisation; 6 = Office for National Statistics.

Objectives	Indicators	Data source and availability*	
Human Capital			
Employment opportunities increase in mariculture, shellfish hand-harvesting, and value-added activities for wild capture fisheries, where these do not exceed levels of sustainable exploitation	(i) Number of new businesses and employees (ii) Number of new shellfish/mariculture licences (iii) Number/extent of mariculture areas	(i) ONS[6] (Nomis) (ii) IFCA (iii) IFCA	B A A
The availability of data on (and therefore knowledge of) environmental, social and economic issues related to marine areas is increased	Number of datasets added to the NDBR centralised database	NDBR	C
Local people are motivated to take part in environmental initiatives	Number of people engaged in beach clean ups Number of people engaged in citizen science	MCS	A
Members of the public are motivated to improve their behaviour around waste disposal	Quantity of locally-derived litter on beaches	MCS Environment Agency	A
Recreational users are motivated to improve their behaviour in order to minimise environmental disturbance	(i) Number of disturbance incidents (ii) Number of accredited recreational boats (iii) Frequency of use of eco-moorings	NDBR	C B C
Fishers and harvesters are more engaged in sustainable fisheries management	Number of fishermen supplying data to the NDBR centralised database	NDBR	C
Social Capital			
Networks for sustainable management of coastal and marine areas are strengthened	Number/diversity of individuals and organisations involved within the NDBR marine governance structure	NDBR	A
Recreational users are more engaged with sustainable management	Number of individuals/businesses adopting and promoting codes of conduct	NDBR	C
Conflict amongst marine users is reduced	Number of infringements of recreational code of conduct and zoning restrictions reported	NDBR	C
The use of citizen science data in decision making is increased	Examples of use in management plans	NDBR, IFCA	C
Manufactured Capital			
New infrastructure for renewable energy and mariculture conforms to sustainability criteria	Number of consent applications adhering to the recommendations	Council, MMO, IFCA	C
New mooring infrastructure is installed to reduce habitat damage due to anchoring and scour (from traditional moorings)	Number of eco-mooring buoys installed	NDBR	C
Financial Capital			
Incomes for fishers/harvesters using low-impact techniques are maintained, and where appropriate increased, through sustainable management of resources and value-added activities	(i) Value of landings/sales (ii) Landings per unit effort	MMO IFCA	B
The economic contribution of recreation and tourism linked to marine and coastal natural capital is maintained	Number of visitors undertaking fishing, outdoor swimming, visits to beaches, coastal walking, wildlife watching and watersports	Natural England	A
New financial mechanisms and products are established to support maritime activities and environmental protection	(i) Number of new blue investment funds (ii) Amount of new blue funding invested in North Devon	NDBR	C

7 Comparing Plan Alternatives

In its current phase, the MNCP does not propose different options for achieving specific plan objectives, as in most cases the objectives relate to very specific high-level tasks (such as the development of codes of conduct or management plans). In the absence of alternative options, this sustainability assessment considers the binary choice of implementing the plan versus not doing so. The expected impacts of implementing the MNCP in terms of the degree to which it will have positive, negative or neutral effects, are made using expert judgment and are summarised in Table 10, which considers both the short (1-5 years) and longer term (more than five years). The assessment of longer term implications is particularly speculative as it relies, for example, on the management plans that are being developed in the first phase of the MNCP resulting in the expected actions that will protect stocks and habitats and support local fisheries. Similarly, the projections assume that governance structures are accepted and maintained and that new financing mechanisms are sufficiently successful to become self-sustaining. More accurate assessment of the outcomes of these strategies and actions will be possible in future phases of the MNCP.

Table 10. The expected direction of impacts of the marine natural capital plan on assets, ecosystem services and benefits, and human, social, and financial capital, when compared to not implementing the plan

Key: Strongly positive – Neutral – Strongly negative; Not assessed

	Short term (1-5yrs)	Longer term (>5yrs)
Natural capital assets		
Geology	Neutral	Neutral
Supralittoral rock	Neutral	Neutral
Supralittoral sediment	Neutral	Neutral
Littoral rock	Neutral	Neutral
Littoral sediment	Neutral	Positive
Saltmarsh	Positive	Strongly positive
Mussel beds	Neutral	Positive
Sublittoral rock	Neutral	Neutral
Sublittoral sediment	Neutral	Positive
Commercial finfish	Neutral	Positive
Crab and lobster	Neutral	Neutral
Wetland birds	Neutral	Positive
Seabirds	Neutral	Neutral
Marine mammals	Neutral	Neutral
Heritage assets		
Designated and non-designated sites	Neutral	Neutral
Ecosystem services and benefits		
Cultivated seafood	Neutral	Positive
Foraged plants	Neutral	Neutral
Game and wild fish	Neutral	Positive
Non-food products from plants, animals & algae:		
Bait	Neutral	Negative
products from cultivated macroalgae	Neutral	Positive
Genetic resources (*mussel spat*)	Neutral	Positive
Energy from non-living sources (*tidal energy*)	Neutral	Positive
Commercial and other transport	Neutral	Neutral
Water quality	Neutral	Positive
Maintenance of nursery populations and habitats	Positive	Strongly positive
Erosion control	Not assessed	Not assessed
Flood protection	Not assessed	Not assessed
Climate regulation	Positive	Positive
Recreation, tourism and other experiential opportunities	Neutral	Neutral
Scientific and educational opportunities	Strongly positive	Strongly positive
Aesthetic	Positive	Positive
Heritage, spiritual and representational significance	Neutral	Neutral
Existence, bequest and option values	Positive	Positive
Social and human capital		
Community networks	Positive	Positive
Knowledge, skills and capabilities	Strongly positive	Strongly positive
Financial capital		
Inward investment	Positive	Strongly positive

In the short term, the principal positive impacts of implementing the MNCP relate to human, social and financial capital, due to the expected strengthening of community networks, improved governance structures, data-sharing, raising awareness and the inward investment from new sustainable finance initiatives. There is the potential for increased positive impact on financial capital in the longer term, as successful funds attract snowballing investment. As the Marine Pioneer, SWEEP and similar recent activities in North Devon have demonstrated, the MNCP area has provided significant opportunities for research, which are expected to continue in the future now that key partnerships have been established. The MNCP is also expected to have a positive impact on education through proposed citizen science and wider engagement initiatives, and on non-use values (existence and bequest) as awareness and understanding of the marine environment increases.

Impacts on natural capital assets, ecosystem services and benefits are largely neutral in the short term. In this inception phase, the MNCP is seeking to put in place the necessary structures to support environmental growth and to aid the development of management plans for specific natural capital assets and ecosystem services, such as those related to fisheries. Thus, direct impacts on the environment in the initial years will be limited. Improvements in the quality of subtidal habitats are expected where eco-moorings are installed and recreational anchoring reduced (and so scour and abrasion impacts decrease) although the spatial scale of these will be small. Management of bait digging is likely to reduce disturbance of intertidal mud. Further increases in the extent or quality of species and habitats may also be secured as sustainable finance allows investment in local conservation initiatives, although these cannot be predicted at this stage.

Even in the longer term when more detailed management plans have been put in place, impacts may not be universally positive. The fisheries management plans are expected to focus on improving the status of species and habitats of particular local importance, and to have impacts in the longer term when the resulting management measures have had time to take effect. Positive impacts are expected for sudtidal sedimentary habitats in inshore areas where fisheries management measures reduce sea bed abrasion and for local stocks which have limited exposure to external pressures. However, these external pressures (such as fishing activity beyond the 6nm limit) as well as climate change will influence the condition, and indeed the continuing presence, of many of the fisheries species important in North Devon. Similarly, the impacts on services and benefits from wild capture fisheries are expected to be broadly neutral even in the longer term, although improved shellfish water quality is likely to increase the economic viability of mussel harvesting resulting in a positive outcome. It is expected that fisheries management plans will seek to maintain the livelihoods of inshore fishermen. Ensuring the continuation of an active inshore fishing fleet in North Devon also secures the connection to the maritime history of the area, preventing a decline in the value of cultural heritage. There is greater potential for measurable positive impact on the supply of cultivated seafood and macro-algae as well as tidal energy if the MNCP intention to support mariculture and other maritime industries is realised through the establishment of new businesses. Similarly, opportunities to re-establish a limited export of mussel spat may be explored, which could also bring economic benefit.

Water quality is expected to improve in the long term as the MNCP supports actions within the North Devon Catchment Management Plan to reduce diffuse pollution, although this is reliant on suitable investment being secured. An increase in the aesthetic quality of the area is also expected. The main land/seascape features (such as cliffs) will not be affected, but a reduction in litter is likely to improve aesthetic quality of specific sites, with improvements potentially occurring quickly as a result of increasing support for ongoing initiatives. The expansion of saltmarsh may also improve visual amenity, although aesthetic judgements are subjective and benefits will depend on relative perception of the current landscape. Increasing the extent and quality of saltmarsh will also provide nursery habitat, with benefits increasing with further expansion in the longer term. Fisheries management plans may have positive impacts on wider nursery habitats in the longer term through the potential protection of important subtidal areas. New areas of saltmarsh will also increase climate regulation, although benefits may be relatively limited, depending on the extent to which current land use promotes carbon uptake. The rate of carbon sequestration in saltmarsh decreases as the habitat matures, tempering the scale of the longer term benefits of continuing to create new areas of saltmarsh in the future. Saltmarsh areas also support significant recreational benefits. Recreation more generally may see a possible slight negative impact for those whose activities are restricted by codes of conduct, although this is likely to be balanced by the increased positive experience of others who benefit from improved environmental quality and noise reduction. There may be a decline in benefits from bait digging, as future management of effort may restrict opportunities for individuals and prohibit expansion.

The implications of the MNCP for erosion control and flood protection have not been assessed. Changes in these services would be related primarily to the expansion of saltmarsh and its role in moderating tidal inundation and attenuating wave action. However, these issues are very complex and require consideration of factors such as whether the saltmarsh replaces hard defences, the extent to which landward expansion is possible, and wider topographical and hydrographic parameters within the estuary. Without sophisticated modelling, it is not possible to make useful judgments about the likelihood of positive or negative effects.

The limited positive benefits of the MNCP are also a reflection of the limitations of local management effectiveness where access rights or species' ranges exceed the governance jurisdiction (as is the case for example with wetland and sea birds and most commercial fisheries species). Ensuring positive outcomes for natural capital in these cases is therefore also dependent on national and international governance. The legislative landscape is particularly uncertain at present (especially for fisheries) with the UK's exit from the European Union and the forthcoming Agriculture, Fisheries and Environment Bills. Local management nonetheless remains extremely important, as any reduction in stress will benefit the resilience of species and habitats, and exemplary management practices may be adopted more widely, increasing the scale of benefits to natural capital.

8 References

Ashley, M., Rees, S.E., Cameron, A. (2018). *North Devon Marine Pioneer Part 1: State of the art report of the links between ecosystem and ecosystem services in the North Devon Marine Pioneer*. A report to WWF-UK by research staff the Marine Institute at Plymouth University

CBD. (2010). *Convention on Biological Diversity. COP 10. Decision X/2.Strategic Plan for Biodiversity 2011-2020*

Cefas, Evironment Agency & Natural Resources Wales (2018). S*almon stocks and fisheries in England and Wales, 2016 Preliminary assessment prepared for ICES, April 2018.* Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/709614/SalmonAssessmentReport-2017-final.pdf.

Forum for the Future (undated). *The Five Capitals* https://www.forumforthefuture.org/the-five-capitals

Hooper, T. L. (2013). *Evaluating the costs and benefits of tidal range energy generation* (Doctoral dissertation, University of Bath).

Historic England. (Undated). Protected Wreck Sites. https://historicengland.org.uk/advice/planning/consents/protected-wreck-sites/ Accessed 09 February 2020

HM Government. (2018). *A green future: our 25 year plan to improve the environment*. London: Department for the Environment Food and Rural Affairs. https://www.gov.uk/government/publications/25-year-environment-plan

HM Government (2011). *UK Marine Policy Statement*.

MMO (2020a). *South West Inshore and South West Offshore Marine Plan* Draft for consultation January 2020. Marine Management Organisation, 56pp.

MMO. (2020b). UK and foreign vessels landings by UK port and UK vessel landings abroad: 2014 to 2018 and 2019 (year to date). Latest update 24 January 2020. Underlying dataset November 2019. https://www.gov.uk/government/statistical-data-sets/uk-and-foreign-vessels-landings-by-uk-port-and-uk-vessel-landings-abroad

MMO (2019). *South West Inshore and Offshore Marine Plans Sustainability Appraisal Part 1: Introduction and Methodology*. Draft Report. A report produced for the Marine Management Organisation, MMO, September 2019, 45pp.

Natural England. (2017). *Designated Sites View: Natural England Conservation Advice for Marine Protected Areas: Advice on Operations, Supplementary Advice on Conservation Objectives*. Natural England. [Online]. Available at: https://designatedsites.naturalengland.org.uk/.

North Devon Council. (undated). *Local Interest List*. http://northdevon.gov.uk/council/strategies-plans-and-policies/environment-and-planning-policies/local-plan/planning-policy-supporting-documents/environment/local-interest-list/ Accessed 09 February 2020

Preece C. 2008. *A Field Guide to the Archaeology of the Taw and Torridge Estuaries*. Edward Gaskell, Bideford. 48pp

Preece C. 2005. A Conflict of Interests: The Fish Traps of the Taw and Torridge Estuaries. *Proceedings of the Devon Archaeological Society*. **63**: 139-165

Rees, S.E., Ashley, M., Cameron, A. (2019). *North Devon Marine Pioneer 2: A Natural Capital Asset and Risk Register*. A SWEEP/WWF-UK report by research staff the Marine Institute at the University of Plymouth

Torridge District Council. (Undated). *The Local Heritage list in Torridge* https://www.torridge.gov.uk/article/11094/The-Local-Heritage-list-in-Torridge Accessed 09 February 2020

Torridge District Council and North Devon Council. (2018). *North Devon and Torridge Local Plan 2011-2031* Adopted October 2018 v1 31 October 2018.

APPENDIX 3: Full classification for the habitat component of natural capital assets

Table A6. The proposed natural capital asset classification for terrestrial, freshwater and intertidal habitats (UK Habitat Classification Working Group, 2018).

Broad group (UKHab Level 2)	Component (UKHab Level 3)	Type (UKHab Level 4)	Additional detail (UKHab Level 5)
Grassland	Acid grasslands	Lowland dry acid grassland	Inland dunes with open grasslands (H2330)
			Other lowland dry acid grassland
		Upland acid grassland	Montane acid grasslands (H6210)
			Other upland acid grasslands
		Bracken	
		Other lowland grassland	
	Calcareous grasslands	Lowland calcareous grassland	Dry grasslands and scrub on chalk or limestone; lowland (H6210)
			Dry grasslands and scrub on chalk or limestone; important orchid sites (H6210)
		Upland calcareous grassland	Alpine and subalpine calcareous grasslands (H6170)
			Species-rich grassland with mat-grass in upland areas (H6230)
			Dry grasslands and scrub on chalk or limestone; upland (H6210)
	Neutral grasslands	Lowland meadows	Lowland hay meadows (H6510)
		Upland hay meadows	Mountain hay meadows (H6520)
		Other neutral grassland	Arrhenatherum neutral grassland
			Lolium-Cynosurus neutral grassland
			Deschampsia neutral grassland
			Holcus-Juncus neutral grassland
	Modified grassland		
Woodland and forest	Broadleaved, mixed and yew woodlands	Upland oakwood	Western acidic oak woodland (H91A0)
		Upland mixed ashwoods	Lime-maple woodlands of rocky slopes (H9180)
			Other upland mixed ashwoods
		Lowland beech and yew woodland	Beech forests on acid soils (H9120)
			Beech forests on neutral to rich soils (H9130)
			Yew-dominated woodland (H91J0)
			Natural box scrub (H5110)
		Wet woodland	Alder woodland on floodplains (H91E0)
			Bog woodland (H91D0)
		Upland birchwoods	
		Lowland mixed deciduous woodland	Dry oak-dominated woodland (H9190)
			Oak-hornbeam forests (H9160)
			Other Lowland mixed deciduous woodland
		Other woodland; broadleaved	Line of trees
			Other broadleaved woodland types
		Other woodland; mixed	Other woodland; mixed; mainly broadleaved
			Other woodland; mixed; mainly conifer
	Coniferous woodlands	Native pine woodlands	Caledonian forest (H91C0)
		Other Scot's Pine woodland	
		Other coniferous woodland	

Broad group (UKHab Level 2)	Component (UKHab Level 3)	Type (UKHab Level 4)	Additional detail (UKHab Level 5)
Heathland and shrub	Dwarf shrub heath	Lowland Heathland	Dry heaths; lowland (H4030)
			Dry coastal heaths with Cornish heath (H4040)
			Wet heathland with cross-leaved heath; lowland (H4010)
			Wet heathland with Dorset heath and cross-leaved heath (H4020)
		Upland Heathland	Dry heaths; upland (H4030)
			Wet heathland with cross-leaved heath; upland (H4010)
		Mountain heaths and willow scrub	Alpine and subalpine heaths (H4060)
			Mountain willow scrub (H4080)
	Hedgerows	Hedgerow (priority habitat)	
		Other hedgerows	
	Dense scrub	Blackthorn scrub	West coast blackthorn scrub
			Other blackthorn scrub
		Hazel scrub	Atlantic hazel
			Other hazel scrub
		Sea buckthorn scrub	Dunes with sea buckthorn (H2160)
			Other sea buckthorn scrub
		Bramble scrub	
		Gorse scrub	
		Hawthorn scrub	
		Rhododendron scrub	
		Mixed scrub	
Wetland	Bog	Blanket bog	Blanket bog (H7130)
			Degraded blanket bog
		Lowland raised bog	Active raised bogs (H7110)
			Degraded raised bog (H7120)
			Other degraded raised bog
	Fen, marsh and swamp	Lowland fens	Calcium-rich fen dominated by great fen sedge (H7210)
			Hard-water springs depositing lime; lowland (H7220)
			Calcium-rich springwater-fed fens; lowland (H7230)
			Transition mires and quaking bogs; lowland (H7140)
		Purple moor grass and rush pastures	Purple moor-grass meadows (H6410)
		Upland flushes, fens and swamps	Alpine pioneer formations (H7240)
			Hard-water springs depositing lime; upland (H7220)
			Calcium-rich springwater-fed fens; upland (H7230)
			Transition mires and quaking bogs; upland (H7140)
		Aquatic marginal vegetation	
		Reedbeds	
		Other swamps	

Broad group (UKHab Level 2)	Component (UKHab Level 3)	Type (UKHab Level 4)	Additional detail (UKHab Level 5)
Cropland	Arable and horticultural	Arable field margins	Arable margins sown with tussocky grasses
			Arable margins sown with wild flowers or a pollen and nectar mix
			Arable margins cultivated annually with an annual flora
			Game bird mix strips and corners
		Temporary grass and clover leys	
		Cereal crops	Winter stubble
			Game bird mix fields
			Other cereal crops
		Non-cereal crops	Miscanthus
			Short-rotation copppice
			Vineyards
			Other non-cereal crops
		Intensive orchards	
		Horticulture	
Urban	Built up areas and gardens	Open Mosaic Habitats on Previously Developed Land	
		Developed land; sealed surface	Buildings
			Other developed land
		Artificial unvegetated, unsealed surface	
		Suburban/ mosaic of developed/ natural surface	
		Built linear features	
Sparsely vegetated land	Inland rock	Inland rock outcrop and scree habitats	Acidic scree (H8110)
			Base-rich scree (H8120)
			Plants in crevices in base-rich rocks (H8210)
			Plants in crevices in acid rocks (H8220)
			Tall herb communities (H6430)
		Limestone pavement	Limestone pavements (H8240)
		Calaminarian grasslands	Grasslands on soils rich in heavy metals (H6130)
		Other inland rock and scree	
	Supralittoral rock	Maritime cliff and slopes	Vegetated sea cliffs (H1230)
			Soft rock sea cliffs
	Supralittoral sediment	Coastal sand dunes	Humid dune slacks (H2190)
			Dunes with juniper thickets (H2550)
			Embryonic shifting dunes (H2110)
			Shifting dunes with marram (H2120)
			Dune grassland (H2130)
			Lime-deficient dune heathland with crowberry (H2140)
			Coastal dune heathland (H2150)
		Coastal vegetated shingle	Perennial vegetation on coastal shingle (H1220)
			Annual vegetation of drift lines (H1210)

Broad group (UKHab Level 2)	Component (UKHab Level 3)	Type (UKHab Level 4)	Additional detail (UKHab Level 5)
Rivers and lakes	Standing open waters and canals	Eutrophic standing waters	Naturally nutrient-rich lakes or lochs (H3150)
			Other eutrophic standing waters
		Mesotrophic lakes	Calcium-rich nutrient-poor lakes lochs and pools (H3140)
		Oligotrophic and dystrophic lakes	Clear-water lakes or lochs with aquatic vegetation (H3130)
			Nutrient-poor shallow waters with aquatic vegetation on sand (H3110)
		Aquifer fed naturally fluctuating water bodies	
		Canals	
	Rivers and streams	Rivers (priority habitat)	Rivers with floating vegetation (H3260)
			Other priority habitat rivers
		Other rivers and streams	
Marine inlets and transitional waters	Littoral rock	Intertidal chalk	
		Sabellaria alveolata reefs	
		Intertidal underboulder communities	
		Estuarine rocky habitats	
		Splash zone with lichens	
		Other littoral rock	
	Littoral sediment	Coastal saltmarsh	Glasswort and other annuals colonising mud and sand (H1310)
			Cord-grass swards (H1320)
			Atlantic salt meadows (H1330)
			Mediterranean saltmarsh scrub (H1420)
		Blue mussel beds on sediment	
		Seagrass beds [Zostera noltii]	
		Intertidal mudflats	Intertidal mudflats and sandflats (H1140)
		Sheltered muddy gravels	
		Peat and clay exposures with piddocks	
		Saline lagoons	Saline lagoons (H1150)
		Beach	

Table A7. Examples of EUNIS habitat codes applicable to habitats at UKHab Level 4 (UK Habitat Classification Working Group, 2018). Based on Potts et al. (2014) and with the caveat that the relationship is not directly equivalent in all cases.

UKHab categories			
Level 3	**Level 4**	**EUNIS code**	**Description**
t1. Littoral rock	t1a. Intertidal chalk	A1.126, A1.243, A1.441, B3.114, B3.115	Littoral chalk communities
	t1b. Sabellaria alveolata reefs	A2.71, A5.612	Honeycomb worm *Sabellaria alveolata* reef
	t1c. Intertidal underboulder communities	A1.2142, A3.2112	Intertidal under boulder communities
	t1d. Estuarine rocky habitats	A1.32	Estuarine rocky habitats
	t1e. Splash zone with lichens	*Supralittoral habitat (not included in Potts et al., 2014)*	
	t1f. Other littoral rock	A1.1	High energy intertidal rock
		A1.2	Moderate energy intertidal rock
		A1.3	Low energy intertidal rock
t2. Littoral sediment	t2a. Coastal saltmarsh	A2.5	Coastal saltmarshes and saline reedbeds
	t2b. Blue mussel beds on sediment	A2.2, A2.7	Blue Mussel beds
	t2c. Seagrass beds [Zostera noltii]	A2.61	Seagrass beds
	t2d. Intertidal mudflats	A2.3	Intertidal mud
		A2.2	Intertidal sand and muddy sand
	t2e. Sheltered muddy gravels	A5.43, A2.41, A2.42, A5.44	Sheltered muddy gravels
	t2f. Peat and clay exposures with piddocks	A1.127, A1.223, A4.231	Peat and clay exposures
	t2g. Saline lagoons	X02	Saline lagoons
	t2h. Beach	A2.2	Intertidal sand and muddy sand

Table A8. The truncated EUNIS classification proposed for identifying key marine habitats (Adapted from https://eunis.eea.europa.eu/habitats-code-browser.jsp)

Broad group (EUNIS Level 1)	Component (EUNIS Level 2)	Type (EUNIS Level 3)	Additional detail (EUNIS Level 4)
Sublittoral habitats	A3. Infralittoral rock and other hard substrata	A3.1. Atlantic and Mediterranean high energy infralittoral rock	A3.11-15. Kelp, seaweed and algal communities
		A3.2. Atlantic and Mediterranean moderate energy infralittoral rock	A3.21-22. Kelp and seaweed communities
			A3.24. Faunal communities
		A3.3. Atlantic and Mediterranean low energy infralittoral rock	A3.31-34. Kelp, fucoid and seaweed communities
			A3.35-36. Faunal communities
		A3.7. Features of infralittoral rock	A3.71. Robust faunal cushions and crusts in surge gullies and caves
			A3.72. Infralittoral fouling seaweed communities
			A3.73. Vents and seeps in infralittoral rock
			A3.74. Caves and overhangs in infralittoral rock
	A4. Circalittoral rock and other hard substrata	A4.1. Atlantic and Mediterranean high energy circalittoral rock	A4.11-13. Faunal, sponge and faunal turf communities
		A4.2. Atlantic and Mediterranean moderate energy circalittoral rock	A4.21. Echinoderms and crustose communities on circalittoral rock
			A4.22. Sabellaria reefs on circalittoral rock
			A4.24. Mussel beds on circalittoral rock
			A4.23, 25, 27. Other faunal communities
		A4.3. Atlantic and Mediterranean low energy circalittoral rock	A4.31 & A4.33. Brachiopod, ascidian and other faunal communities
		A4.7. Features of circalittoral rock	A4.71. Communities of circalittoral caves and overhangs
			A4.72. Circalittoral fouling faunal communities
			A4.73. Vents and seeps in circalittoral rock
	A5. Sublittoral sediment	A5.1. Sublittoral coarse sediment	
		A5.2. Sublittoral sand	
		A5.3. Sublittoral mud	
		A5.4. Sublittoral mixed sediments	
		A5.5. Sublittoral macrophyte-dominated sediment	A5.51. Maerl beds
			A5.52. Kelp and seaweed communities on sublittoral sediment
			A5.53. Sublittoral seagrass beds
			A5.54. Angiosperm communities in reduced salinity
		A5.6. Sublittoral biogenic reefs	A5.61. Sublittoral polychaete worm reefs on sediment
			A5.62. Sublittoral mussel beds on sediment
			A5.63. Circalittoral coral reefs
		A5.7. Features of sublittoral sediments	A5.71. Seeps and vents in sublittoral sediments
			A5.72. Organically-enriched or anoxic sublittoral habitats
	A7. Pelagic water column	A7.1. Neuston	
		A7.2. Completely mixed water column with reduced salinity	
		A7.3. Completely mixed water column with full salinity	
		A7.4. Partially mixed water column with reduced salinity and medium or long residence time	
		A7.5. Unstratified water column with reduced salinity	
		A7.6. Vertically stratified water column with reduced salinity	
		A7.7. Fronts in reduced salinity water column	
		A7.8. Unstratified water column with full salinity	
		A7.9. Vertically stratified water column with full salinity	
		A7.A. Fronts in full salinity water column	

APPENDIX 4: Common International Classification of Ecosystem Services

Table A9. A summary of the Common International Classification of Ecosystem Services (CICES) v.5.1 (Haines-Young and Potschin, 2018)

Ecosystem Services		Examples*
Provisioning		
Food	• Cultivated and wild harvested terrestrial and aquatic plants • Reared and wild capture animals and aquatic animals • Mineral and non-mineral substances	• Wheat, edible seaweed • Beef cattle, mussels • Salt
Fibres and other materials (for direct use)	• Cultivated and wild harvested terrestrial and aquatic plants • Reared and wild capture animals and aquatic animals • Mineral and non-mineral substances	• Timber • Oyster pearls, hides • Pigments
Energy	• Cultivated and wild harvested terrestrial and aquatic plants • Reared and wild capture animals and aquatic animals • Surface and ground water • Coastal and marine waters • Mineral and non-mineral substances	• Biofuel crops • Biofuel from manure • Hydro-electricity • Tidal and wave power • Wind, solar, geothermal energy
Genetic materials	• Seeds, spores and other plant and animal material • Higher and lower plants and wild animals (whole organisms) • Individual genes	• Spat for aquaculture • Animals in breeding programmes • For pharmaceutical products
Water (surface and ground)	• Drinking • Non-drinking purposes	• Drinking water • Agricultural irrigation
Regulation and Maintenance		
Mediation of waste or toxic substances	• Bioremediation by micro-organisms, algae, plants, and animals • Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals and mineral substances • Dilution by freshwater, marine systems and the atmosphere	• Bacterial breakdown of oil • Trapping of dust by urban trees and particles by salt marsh • Use as a pollution sink
Mediation of nuisances	• Smell reduction • Noise attenuation • Visual screening	• Vegetated shelter belts around animal lots, motorways, industrial structures • Screening effect of topography
Regulation of flows and extreme events	• Control of erosion rates • Control of mass movement • Flood control • Coastal protection • Wind protection • Fire protection	• Vegetation providing soil stability • Forest cover mitigating avalanche • Vegetation slowing water release, natural levees providing protection • Biogenic reefs and sand bars attenuating waves • Trees/topography providing wind break • Fire belts in forests
Lifecycle maintenance, gene pool protection	• Pollination (or gamete dispersal in a marine context) • Seed dispersal • Maintaining nursery populations	• Habitat for native pollinators • Acorn dispersal by Jays • Seaweed rafts as juvenile fish habitat
Pest and disease control	• Pest control (including invasive species) • Disease control	• Recovery of predator populations • Microbes to control crop diseases
Regulation of soil quality	• Weathering processes • Decomposition and fixing processes	• Inorganic nutrient release • Nitrogen fixation by legumes
Regulation of water quality	• Regulation of freshwater • Regulation of salt water	• Buffer strips to filter nutrients • Eutrophication resistance/resilience
Regulation of atmospheric conditions	• Carbon sequestration • Temperature regulation	• Carbon storage by forests, peatlands • Cooling provided by urban trees
Cultural		
Direct physical and experiential interactions	• Active recreation/leisure interaction • Passive or observational recreation/leisure interaction • Scientific investigation or creation of traditional knowledge • Education and training • Culture and heritage • Aesthetic experiences	• Opportunities for hiking, climbing • Opportunities for wildlife watching • Opportunities for research/study • Volunteer conservation activities • Ancient woodlands • Areas of outstanding natural beauty
Indirect, remote interactions	• Symbolic meanings • Sacred or religious meanings • Entertainment or representation • Existence, bequest and option value	• Species used as national symbols • Totemic species, iconic mountains • Media features • Wilderness areas, charismatic or endangered species

* It is important to note that the original wording within CICES emphasises that ecosystem services are ecological end points (e.g. standing crops of wheat, not the harvested quantity).

Table A10. The complete list of ecosystem service classes defined by the Common International Classification of Ecosystem Services (CICES; Haines-Young and Potschin, 2018)

a) *Provisioning services*

Provisioning (Biotic)

- Biomass
  - Cultivated terrestrial plants for nutrition, materials or energy
    - Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes
    - Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials)
    - Cultivated plants (including fungi, algae) grown as a source of energy
  - Cultivated aquatic plants for nutrition, materials or energy
    - Plants cultivated by in- situ aquaculture grown for nutritional purposes
    - Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials)
    - Plants cultivated by in- situ aquaculture grown as an energy source
  - Reared animals for nutrition, materials or energy
    - Animals reared for nutritional purposes
    - Fibres and other materials from reared animals for direct use or processing (excluding genetic materials)
    - Animals reared to provide energy (including mechanical)
  - Reared aquatic animals for nutrition, materials or energy
    - Animals reared by in-situ aquaculture for nutritional purposes
    - Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials)
    - Animals reared by in-situ aquaculture as an energy source
  - Wild plants (terrestrial and aquatic) for nutrition, materials or energy
    - Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition
    - Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)
    - Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy
  - Wild animals (terrestrial and aquatic) for nutrition, materials or energy
    - Wild animals (terrestrial and aquatic) used for nutritional purposes
    - Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)
    - Wild animals (terrestrial and aquatic) used as a source of energy
- Genetic material from all biota (including seed, spore or gamete production)
  - Genetic material from plants, algae or fungi
    - Seeds, spores and other plant materials collected for maintaining or establishing a population
    - Higher and lower plants (whole organisms) used to breed new strains or varieties
    - Individual genes extracted from higher and lower plants for the design and construction of new biological entities
  - Genetic material from animals
    - Animal material collected for the purposes of maintaining or establishing a population
    - Wild animals (whole organisms) used to breed new strains or varieties
    - Individual genes extracted from organisms for the design and construction of new biological entities

Provisioning (Abiotic)

- Water
  - Surface water used for nutrition, materials or energy
    - Surface water for drinking
    - Surface water used as a material (non-drinking purposes)
    - Freshwater surface water used as an energy source
    - Coastal and marine water used as energy source
  - Ground water used for nutrition, materials or energy
    - Ground water (and subsurface) used as a material (non-drinking purposes)
    - Ground water (and subsurface) used as a material (non-drinking purposes)
    - Ground water (and subsurface) used as an energy source
- Non-aqueous natural abiotic ecosystem outputs
  - Mineral substances used for nutrition, materials or energy
    - Mineral substances used for nutritional purposes
    - Mineral substances used for material purposes
    - Mineral substances used for as an energy source
  - Non-mineral substances or ecosystem properties used for nutrition, materials or energy
    - Non-mineral substances or ecosystem properties used for nutritional purposes
    - Non-mineral substances used for materials
    - Wind energy
    - Solar energy
    - Geothermal energy

b) Regulation and Maintenance

Regulation & Maintenance (Biotic)

- Transformation of biochemical or physical inputs to ecosystems
  - Mediation of wastes or toxic substances of anthropogenic origin by living processes
    - Bio-remediation by micro-organisms, algae, plants, and animals
    - Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals
  - Mediation of nuisances of anthropogenic origin
    - Smell reduction
    - Noise attenuation
    - Visual screening
- Regulation of physical, chemical, biological conditions
  - Regulation of baseline flows and extreme events
    - Control of erosion rates
    - Buffering and attenuation of mass movement
    - Hydrological cycle and water flow regulation (Including flood control, and coastal protection)
    - Wind protection
    - Fire protection
  - Lifecycle maintenance, habitat and gene pool protection
    - Pollination (or 'gamete' dispersal in a marine context)
    - Seed dispersal
    - Maintaining nursery populations and habitats (Including gene pool protection)
  - Pest and disease control
    - Pest control (including invasive species)
    - Disease control
  - Regulation of soil quality
    - Weathering processes and their effect on soil quality
    - Decomposition and fixing processes and their effect on soil quality
  - Water conditions
    - Regulation of the chemical condition of freshwaters by living processes
    - Regulation of the chemical condition of salt waters by living processes
  - Atmospheric composition and conditions
    - Regulation of chemical composition of atmosphere and oceans
    - Regulation of temperature and humidity, including ventilation and transpiration

Regulation & Maintenance (Abiotic)

- Transformation of biochemical or physical inputs to ecosystems
  - Mediation of waste, toxics and other nuisances by non-living processes
    - Dilution by freshwater and marine ecosystems
    - Dilution by atmosphere
    - Mediation by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)
  - Mediation of nuisances of anthropogenic origin
    - Mediation of nuisances by abiotic structures or processes
- Regulation of physical, chemical, biological conditions
  - Regulation of baseline flows and extreme events
    - Mass flows
    - Liquid flows
    - Gaseous flows
  - Maintenance of physical, chemical, abiotic conditions
    - Maintenance and regulation by inorganic natural chemical and physical processes

c) Cultural services

Cultural (Biotic)

- Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting
  - Physical and experiential interactions with natural environment
    - Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions
    - Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions
  - Intellectual and representative interactions with natural environment
    - Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge
    - Characteristics of living systems that enable education and training
    - Characteristics of living systems that are resonant in terms of culture or heritage
    - Characteristics of living systems that enable aesthetic experiences
- Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting
  - Spiritual, symbolic and other interactions with natural environment
    - Elements of living systems that have symbolic meaning
    - Elements of living systems that have sacred or religious meaning
    - Elements of living systems used for entertainment or representation
  - Other biotic characteristics that have a non-use value
    - Characteristics or features of living systems that have an existence value
    - Characteristics or features of living systems that have an option or bequest value

Cultural (Abiotic)

- Direct, in-situ and outdoor interactions with natural physical systems that depend on presence in the environmental setting
  - Physical and experiential interactions with natural abiotic components of the environment
    - Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions
  - Intellectual and representative interactions with abiotic components of the natural environment
    - Natural, abiotic characteristics of nature that enable intellectual interactions
- Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting
  - Spiritual, symbolic and other interactions with the abiotic components of the natural environment
    - Natural, abiotic characteristics of nature that enable spiritual, symbolic and other interactions
  - Other abiotic characteristics that have a non-use value
    - Natural, abiotic characteristics or features of nature that have either an existence, option or bequest value

Note. *The arrangement of the hierarchy levels is as follows:*

Section

- Division
  - Group
    - Class

APPENDIX 5: Ecosystem Services Classification Hierarchy

Table A11. The complete ecosystem service hierarchy proposed for Sustainability Appraisal, (developed from Sunderland et al., 2018 and Haines-Young and Potschin, 2018).

a) Provisioning services

Level 2	Level 3	Level 4 (CICES class)
Food	Cultivated food crops	Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes
	Livestock	Animals reared for nutritional purposes
	Cultivated seafood	Plants cultivated by in- situ aquaculture grown for nutritional purposes
		Animals reared by in-situ aquaculture for nutritional purposes
	Foraged plants	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition
	Game and wild fish	Wild animals (terrestrial and aquatic) used for nutritional purposes
	Food products from non-living sources	Mineral substances used for nutritional purposes
		Non-mineral substances or ecosystem properties used for nutritional purposes
Materials	Non-food products from plants, animals & algae	Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials)
		Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials)
		Fibres and other materials from reared animals for direct use or processing (excluding genetic materials)
		Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials)
		Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)
		Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)
	Non-food products from non-living sources	Mineral substances used for material purposes
		Non-mineral substances used for materials
	Genetic resources	Seeds, spores and other plant materials collected for maintaining or establishing a population
		Higher and lower plants (whole organisms) used to breed new strains or varieties
		Individual genes extracted from higher and lower plants for the design and construction of new biological entities
		Animal material collected for the purposes of maintaining or establishing a population
		Wild animals (whole organisms) used to breed new strains or varieties
		Individual genes extracted from organisms for the design and construction of new biological entities
Water	Water supply	Surface water for drinking
		Surface water used as a material (non-drinking purposes)
		Ground (and subsurface) water for drinking
		Ground water (and subsurface) used as a material (non-drinking purposes)
Energy	Energy from non-living sources	Freshwater surface water used as an energy source
		Coastal and marine water used as energy source
		Ground water (and subsurface) used as an energy source
		Wind energy
		Solar energy
		Geothermal
		Mineral substances used as an energy source
		Other mineral or non-mineral substances or ecosystem properties used for nutrition, materials or energy
	Energy from plants	Cultivated plants (including fungi, algae) grown as a source of energy
		Plants cultivated by in- situ aquaculture grown as an energy source
		Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy
	Energy from animals	Animals reared to provide energy (including mechanical)
		Animals reared by in-situ aquaculture as an energy source
		Wild animals (terrestrial and aquatic) used as a source of energy
Carrier	Commercial and other transport	*Not included within CICES*

b) Regulation and maintenance services

Level 2	Level 3	Level 4 (CICES class)
Environmental quality	Water quality	Bio-remediation by micro-organisms, algae, plants, and animals
		Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals
		Regulation of the chemical condition of freshwaters by living processes
		Regulation of the chemical condition of salt waters by living processes
		Dilution by freshwater and marine ecosystems
		Mediation by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)
		Mediation of nuisances by abiotic structures or processes
		Maintenance and regulation by inorganic natural chemical and physical processes
	Air quality	Bio-remediation by micro-organisms, algae, plants, and animals
		Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals
		Smell reduction
		Dilution by atmosphere
		Mediation by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)
	Soil health	Weathering processes and their effect on soil quality
		Decomposition and fixing processes and their effect on soil quality
Maintaining wild populations	Pollination & seed dispersal	Pollination (or 'gamete' dispersal in a marine context)
		Seed dispersal
	Maintenance of nursery populations and habitats	Maintaining nursery populations and habitats (Including gene pool protection)
Hazard and nuisance reduction	Erosion control	Control of erosion rates
		Buffering and attenuation of mass movement
		Mass flows
	Flood protection	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)
		Liquid flows
	Storm protection	Wind protection
		Gaseous flows
	Pest and disease control	Pest control (including invasive species)
		Disease control
	Fire protection	Fire protection
	Noise reduction	Noise attenuation
	Visual screening	Visual screening
Climate regulation	Climate regulation	Regulation of chemical composition of atmosphere and oceans
		Regulation of temperature and humidity, including ventilation and transpiration

c) Cultural services

Level 2	Level 3	Level 4 (CICES class)
Physical, experiential and intellectual interactions	Recreation, tourism, other experiential opportunities	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions
		Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions
		Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions
	Scientific, educational opportunities	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge
		Characteristics of living systems that enable education and training
Cultural significance of nature	Aesthetic	Characteristics of living systems that enable aesthetic experiences
	Heritage, spiritual and representational significance	Characteristics of living systems that are resonant in terms of culture or heritage
		Elements of living systems that have symbolic meaning
		Elements of living systems that have sacred or religious meaning
		Elements of living systems used for entertainment or representation
		Natural, abiotic characteristics of nature that enable intellectual interactions
		Natural, abiotic characteristics of nature that enable spiritual, symbolic and other interactions
Non-use values	Existence, bequest and option values	Characteristics or features of living systems that have an existence value
		Characteristics or features of living systems that have an option or bequest value
		Natural, abiotic characteristics or features of nature that have either an existence, option or bequest value

SWEEP 002 short report
on the recreational importance of selected coastal-facing locations in the Plymouth area

Dr. Michela Faccioli and Dr. Sara Zonneveld
(University of Exeter)

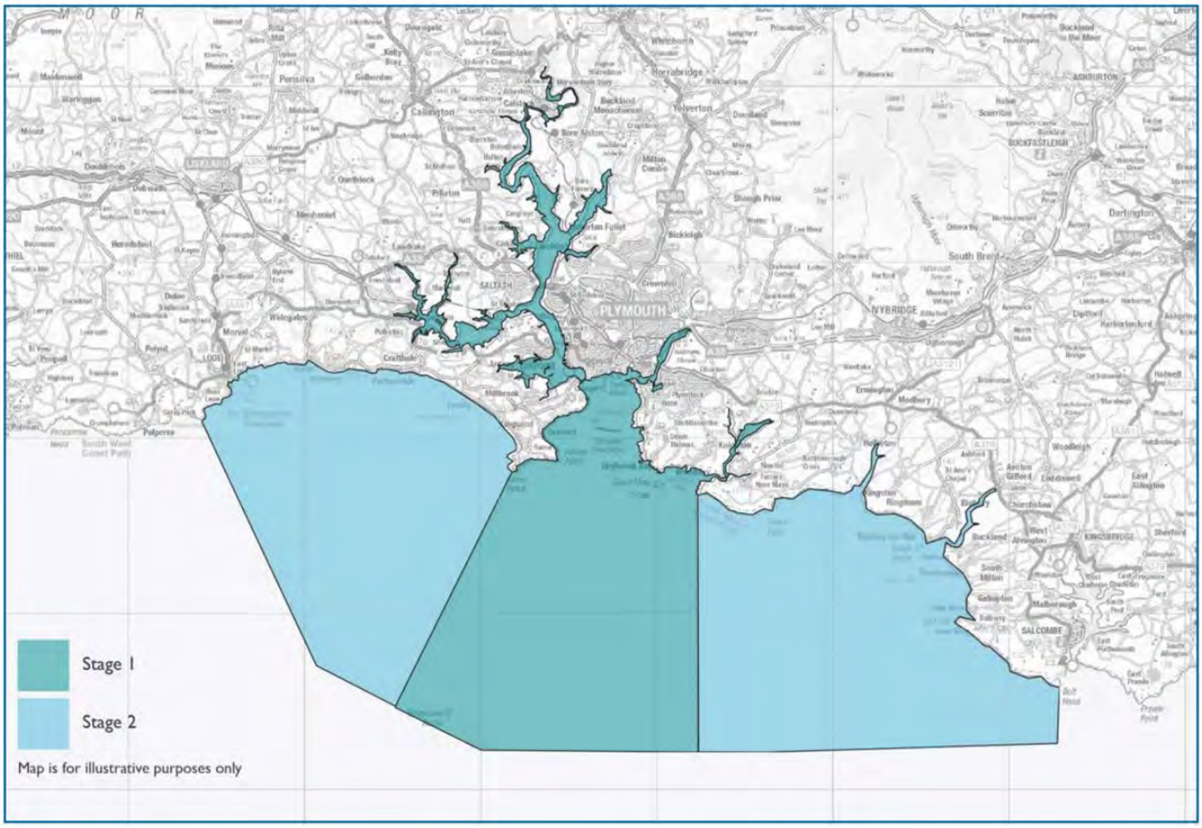
Acknowledgements:

This research was funded by the Natural Environment Research Council (NERC) as part of the SWEEP programme (South West Partnership for Environment and Economic Prosperity) [grant number NE/P011217/1].

Scope:

This short document aims to summarise information on visitor numbers and recreational values associated with selected coastal-facing locations of interest in the Plymouth area. This information can be used to set a baseline regarding the current recreational importance of locations that will be part of the newly constituted National Marine Park in Plymouth. The locations of interest have been identified in discussion with colleagues from Plymouth University and include:

1) Mt Edgcumbe
2) the city (the ferry to Laira bridge)
3) The coast path from Laira bridge round to the National Marne Park Phase one boundary on the east of the city (see Map below)



[Source: https://www.plymouth.gov.uk/sites/default/files/PlymouthSoundNationalMarineParkDocument.pdf]

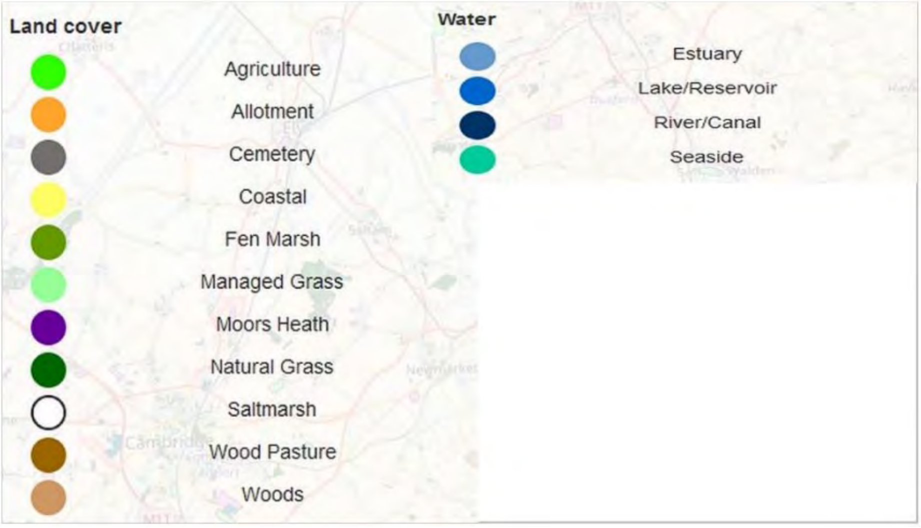
The present document, in particular, summarises the visitor numbers and recreational values associated with the existence of coastal paths, access points and beaches for each of the three case study locations considered (where applicable). The reported information was obtained using the freely available tool ORVal (Outdoor Recreation Valuation Tool) developed by the LEEP Institute at the University of Exeter: https://www.leep.exeter.ac.uk/orval/ (Day and Smith 2018).

Methodology:

This section will present more details on the technical features of ORVal, to provide the reader with a user-friendly but still technical understanding of how this tool works and how it was used to carry out the analysis reported in this document. Many of the details come from a condensed version of the more extensive help and technical support documents produced by the authors of the tool (B. Day and G. Smith from the University of Exeter) and publicly available from: https://www.leep.exeter.ac.uk/orval/pdf-reports/ORVal2_User_Guide.pdf and https://www.leep.exeter.ac.uk/orval/pdf-reports/ORValII_Modelling_Report.pdf.

ORVal is a map-based interface that allows to learn more about the distribution of currently accessible greenspaces in England and Wales, their characteristics and the visitation numbers and welfare values associated with a recreational day visit to specific greenspaces. ORVal relies on a sophisticated model, which combines different layers of data:

- **Visitation information** - based on 2009-2016 data from the Monitor of Engagement with the Natural Environment (MENE) survey for England and the Welsh Outdoor Recreation Survey (WORS) for Wales. Survey data on visitors include information on the visited location, the activities carried out at the location, the respondent's place of residence, their socio-demographic profile (including social grade, as a proxy for income) and mode of transport (whether the visitor accessed the site by car or on foot).
- **Greenspace information**. The greenspaces identified as Recreational Sites in the ORVal map are of three different types: areas (i.e. accessible greenspace contained within well-defined boundaries), paths (i.e. confined walkable routes of passage) or beaches.
- **Land cover data**. For each recreational site, information on the type of land cover is also reported. In ORVal fifteen different types of land cover are considered, as reported here:



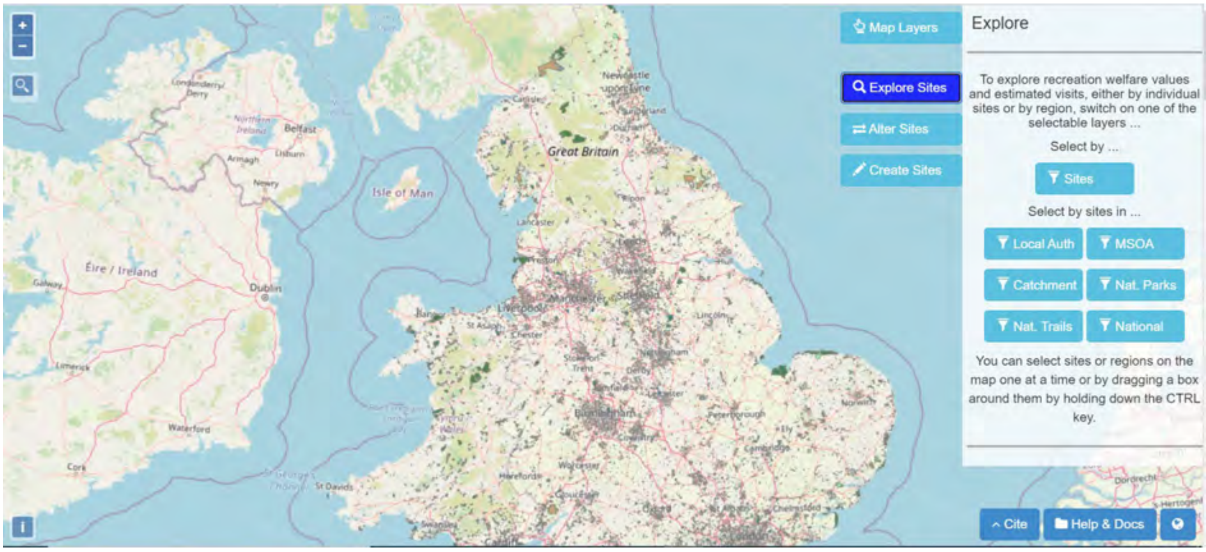
- **Special designation areas**. An additional layer of data reports information regarding whether the site of interest is subject to any special designation (i.e. whether it belongs to a National Park, National Trail, Nature Reserve, etc.)
- **Background map**. The background map layer underlying the map-based interface in ORVal is based on OpenStreetMaps.

The ORVal tool relies on a sophisticated travel cost model, which estimates the probability for a particular person to visit a particular greenspace with particular characteristics. The fundamental assumption of the model is that a visitor chooses to visit a given greenspace because the "welfare" (or sense of pleasure/wellbeing) experienced when taking that trip exceeds the costs of taking the trip[1]

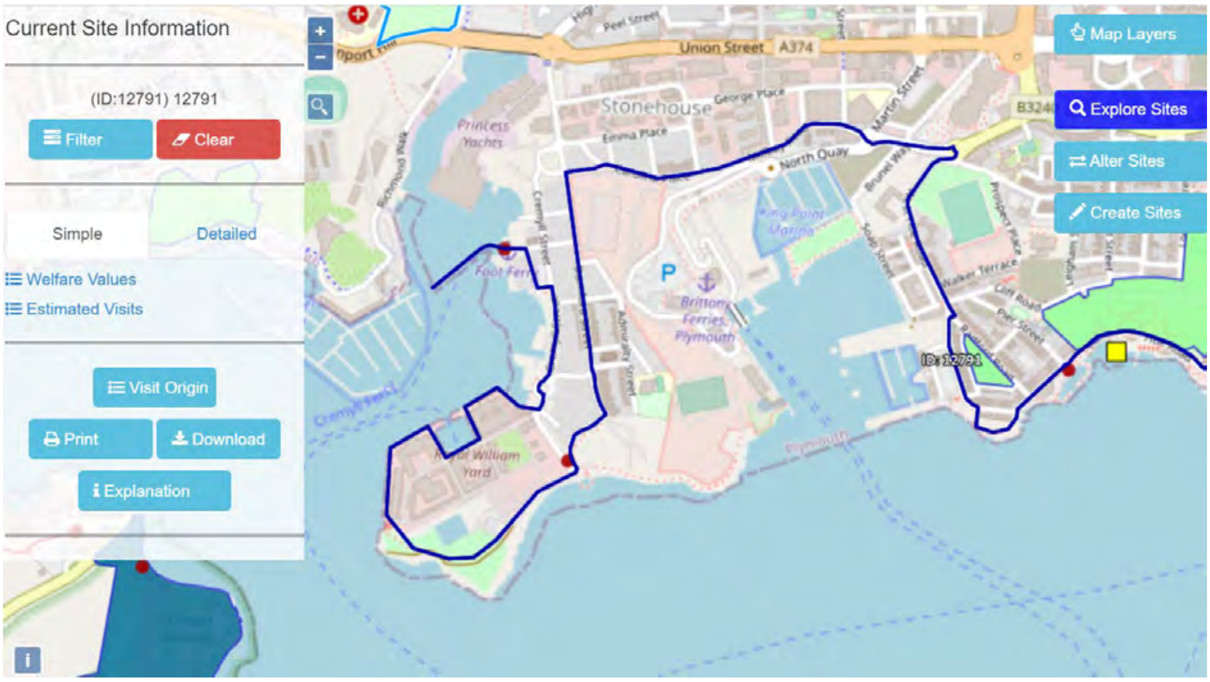
[1] In ORVal, the costs of taking a trip to a given greenspace are calculated as the sum of the travel costs (e.g. costs of petrol, entry tickets, etc.) and, if applicable, the opportunity costs of travel time (i.e. the costs of giving up e.g. time at work to travel).

as well as the “welfare” of doing anything else. The model also contextualises visitors’ choices by considering all alternative greenspaces which the person had available but decided not to visit. In these terms, if people are willing to take longer trips to visit a specific location, this provides an indication that the value placed on visiting that greenspace is higher compared to the value of visiting alternative sites closer to home. Similarly, choosing to visit a specific site over other greenspaces with similar characteristics (e.g. in terms of land cover type, distance, degree of accessibility by mode of transport, etc.) implies that the chosen site is more valuable or attractive for the recreationist.

The ORVal tool has many functionalities, but we will only focus on the feature that we used in this report: the ‘explore sites’ function. This function can be accessed by clicking on the ‘Explore Sites’ button on the right-hand site of the ORVal homepage. This feature allows to estimate the degree of usage of given sites and the welfare values associated with the recreational enjoyment of the different existing greenspaces.



For the purposes of our analysis, we mostly focused on information at ‘Sites’ level. In ORVal, after clicking on the [Sites] button, a panel opens on the left-hand side of the page, called “Current Site Information”. To visualise the ORVal model output, a specific area/path/beach location (or set thereof) need to be selected on the map. On the ORVal map, areas are represented by coloured polygons (e.g. ), paths are indicated by red lines), access points by red dots (i.e.) and beaches are marked by). Once the location (or locations) of interest is (are) selected, the site ID will automatically appear in the Current Site Information window (as well as on the map), so the reader can have a clear idea regarding what sites have been selected (which will turn ‘blue’ after selection) and what locations the estimates refer to. Please, see example below:



The information on visitation numbers and welfare values is then provided as totals (by clicking on the ‘simple’ tab) or in disaggregate form (by clicking on the ‘detailed’ tab). In the detailed tab, information on estimated visits and welfare values are, in fact, not only reported in aggregate form (as totals) but also by socio-economic group (AB, C1, C2 and DE, based on National Readership Survey social grades classification)[2] and transport mode (by car or not by car). Further details about the land cover characteristics of the selected site(s), the type of designation (if applicable), any points of interest present and the OS Greenspace ID details for the site(s) are also reported in the bottom part of the ‘Detailed’ tab.

[2] https://en.wikipedia.org/wiki/NRS_social_grade

Highlight of the results:

This short report summarises information about the baseline number of visitors and welfare values associated with the recreational enjoyment of three popular areas in Plymouth: 1) Mount Edgcumbe; 2) the city (the ferry to Laira bridge) and 3) the coast path from Laira bridge round to the National Marine Park Phase I boundary (east of the city). It's important to know that the figures provided by ORVal are per year and they refer to the estimated number of visitors and values associated with the current recreational use of the greenspaces of interest, relative to a scenario in which the greenspace did not exist. This section only provides the highlight results. For full details on the specific output generated by ORVal (at site, type of greenspace and socio-economic level), please refer to the Appendix at the end of this document.

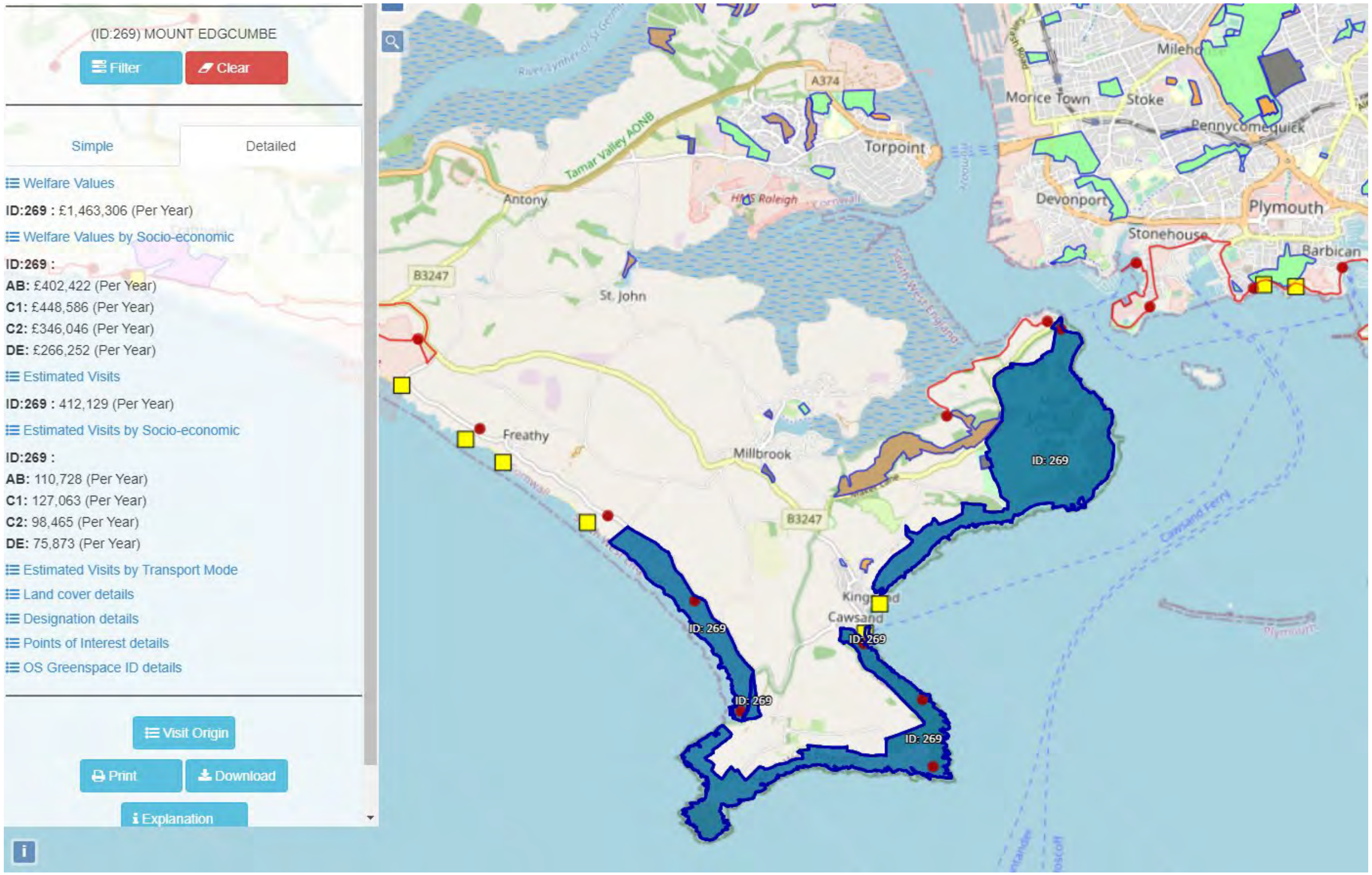
Out of the three case study sites of interest, the most valuable location (from a recreational point of view) is the city stretch (ferry to Laira bridge). This is not too surprising given the concentration of people living in this area and visiting it for recreational purposes. The existence of a coastal path, access points to the coastal path and the beaches in this area is estimated to generate £12,667,964 (per year) in terms of welfare for visitors and attract about 2,794,831 day visitors (per year). As a comparison, visiting the coastal area and beaches at Mt. Edgcumbe generates an estimated total welfare for visitors of £2,953,230 (per year) and attracts about 671,227 visitors (per year). Similarly, the coastal path, access points to the coastal path and beaches from Laira bridge to the National Marine Park (Phase I boundary) are estimated to generate £5,942,554 (per year) in terms of total welfare for visitors and attract around 1,415,655 day visitors (per year).

Regardless of the location considered, beaches are a very valuable recreational feature of the greenspace for visitors. In all three case study areas of interest, beaches provide between 37% of the total recreational value of the location (in the case of the coast path from Laira bridge to the National Marina Phase I boundary) and 58% of the total recreational value of the site (in the case of the city stretch).

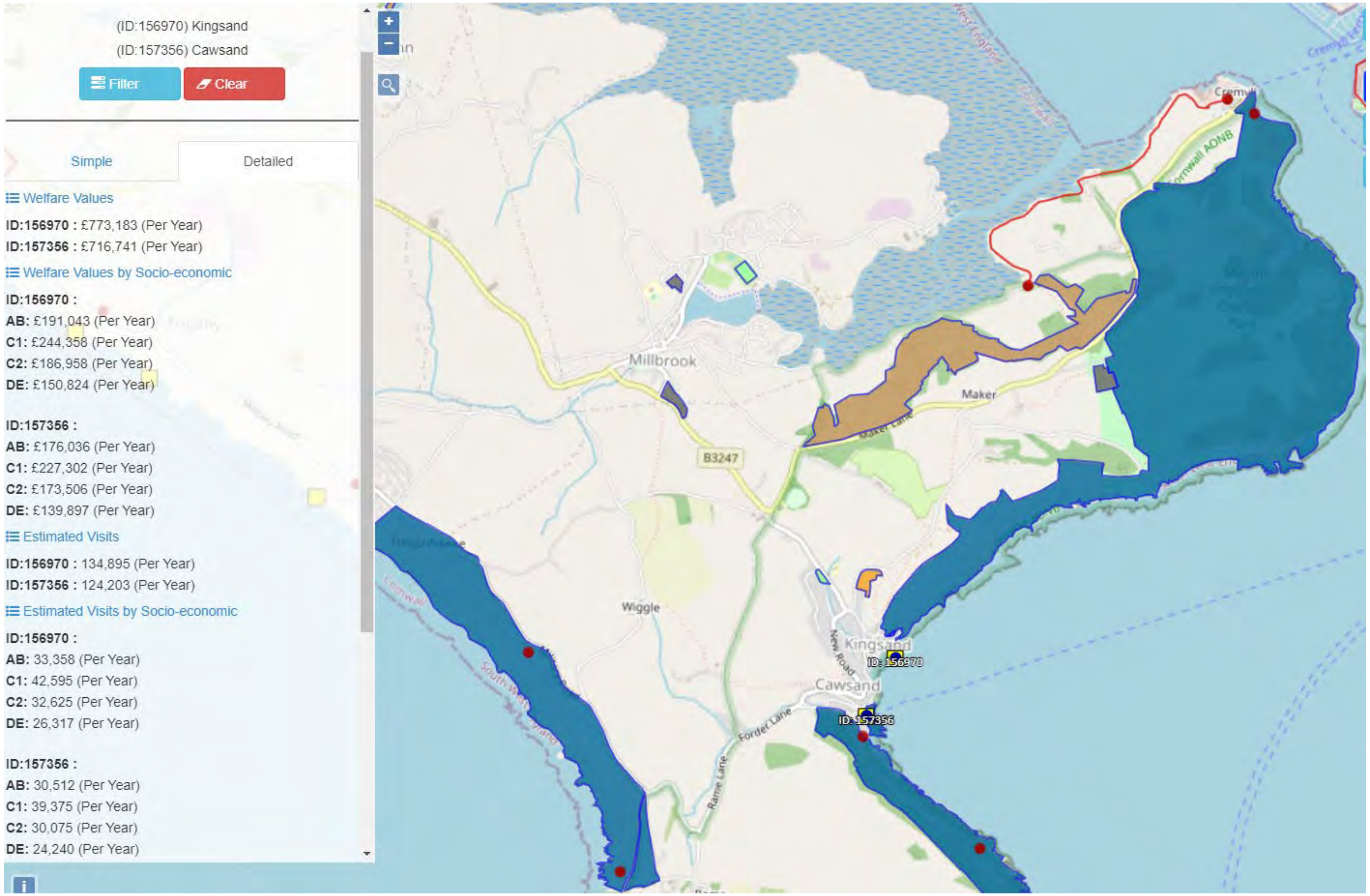
In terms of the distribution of the recreational visitation rates and values across the different socio-demographic groups (approximated by the social grades' classification, ranging from "AB" referring to the higher income groups, to "DE", referring the lower income group), some interesting patterns can also be observed in the data. The recreational benefits supplied by the Mt Edgcumbe area seem to accrue proportionately less to the people in lower socio-economic groups (DE) compared to other income groups. In the city stretch, the group of visitors that appear to display higher rates of visitation to the area and higher recreational benefits is the C1 (middle income) group, while less prominent differences are to be observed across the remaining socio-economic groups. In the area east of the city (from Laira bridge to the National Marine Park Phase I boundary) visitation rates and the welfare accruing from outdoor visitation of the greenspaces seems to be highest for visitors in the C1 socio-economic group but lowest for visitors in the lower socio-economic group (DE). While a deeper analysis is required to better understand the distribution of recreational benefits across groups of visitors, this analysis provides a first indication of possible differences across socio-economic segments of society, in terms of their access to and interaction with greenspaces.

Appendix:

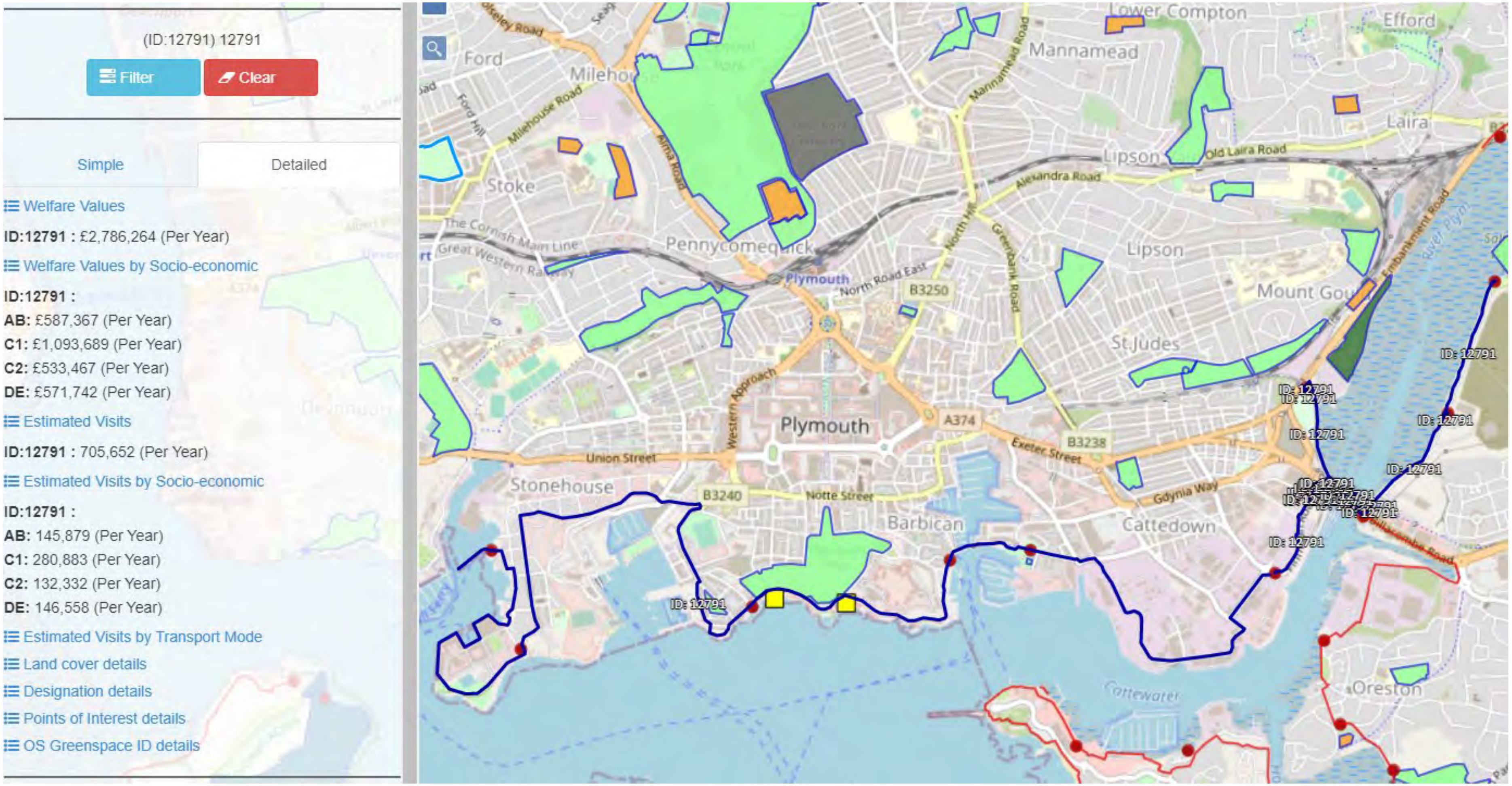
Mount Edgcumbe (blue area below, ID 269): **Baseline situation -** coastal area



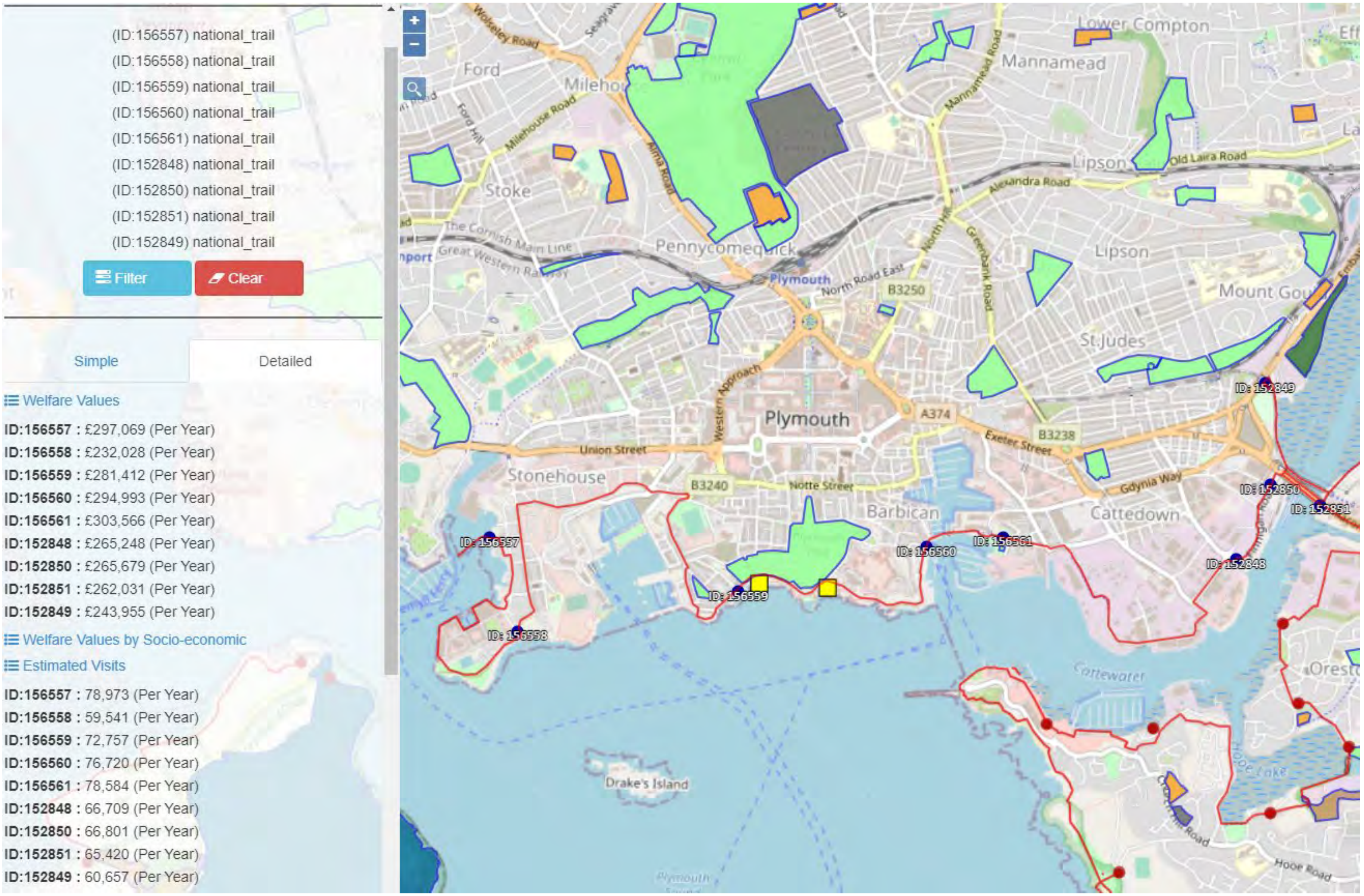
Mount Edgcumbe: **Baseline situation –** beaches (Kingsand and Cawsand)



The city (the ferry to Laira bridge) – baseline - coastal path (dark blue line)



The city (the ferry to Laira bridge) – baseline – access points to coastal path (dark blue points below)



Welfare Values by socio-economic group:

ID:156557 :
AB: £59,103 (Per Year)
C1: £109,019 (Per Year)
C2: £58,132 (Per Year)
DE: £70,816 (Per Year)

ID:156558 :
AB: £47,289 (Per Year)
C1: £83,860 (Per Year)
C2: £46,029 (Per Year)
DE: £54,850 (Per Year)

ID:156559 :
AB: £57,961 (Per Year)
C1: £111,194 (Per Year)
C2: £52,010 (Per Year)
DE: £60,247 (Per Year)

ID:156560 :
AB: £60,651 (Per Year)
C1: £120,135 (Per Year)
C2: £53,238 (Per Year)
DE: £60,969 (Per Year)

ID:156561 :
AB: £62,799 (Per Year)
C1: £126,581 (Per Year)
C2: £54,885 (Per Year)
DE: £59,302 (Per Year)

ID:152848 :

AB: £57,077 (Per Year)
C1: £107,027 (Per Year)
C2: £50,121 (Per Year)
DE: £51,023 (Per Year)

ID:152850 :
AB: £56,658 (Per Year)
C1: £107,241 (Per Year)
C2: £50,302 (Per Year)
DE: £51,478 (Per Year)

ID:152851 :
AB: £58,008 (Per Year)
C1: £103,373 (Per Year)
C2: £51,070 (Per Year)
DE: £49,579 (Per Year)

ID:152849 :
AB: £51,443 (Per Year)
C1: £94,761 (Per Year)
C2: £49,140 (Per Year)
DE: £48,611 (Per Year)

Estimated visits by socio-demographics:

ID:156557 :
AB: 15,430 (Per Year)
C1: 28,901 (Per Year)
C2: 15,279 (Per Year)
DE: 19,362 (Per Year)

ID:156558 :
AB: 11,942 (Per Year)

C1: 21,408 (Per Year)
C2: 11,682 (Per Year)
DE: 14,509 (Per Year)

ID:156559 :
AB: 14,754 (Per Year)
C1: 29,206 (Per Year)
C2: 13,067 (Per Year)
DE: 15,730 (Per Year)

ID:156560 :
AB: 15,460 (Per Year)
C1: 31,928 (Per Year)
C2: 13,404 (Per Year)
DE: 15,928 (Per Year)

ID:156561 :
AB: 15,871 (Per Year)
C1: 33,687 (Per Year)
C2: 13,719 (Per Year)
DE: 15,308 (Per Year)

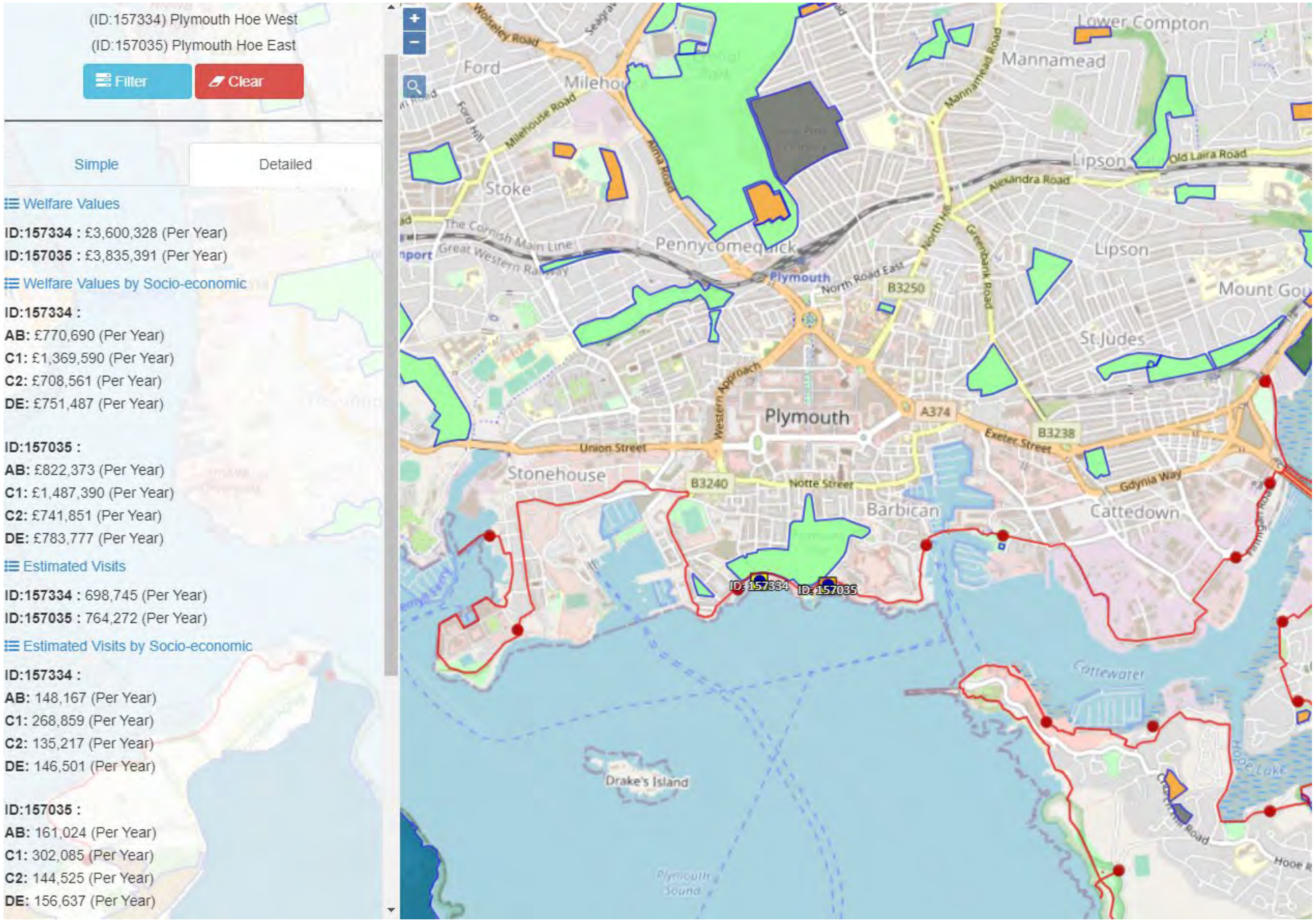
ID:152848 :
AB: 14,063 (Per Year)
C1: 27,450 (Per Year)
C2: 12,320 (Per Year)
DE: 12,876 (Per Year)

ID:152850 :
AB: 13,938 (Per Year)
C1: 27,507 (Per Year)
C2: 12,361 (Per Year)
DE: 12,995 (Per Year)

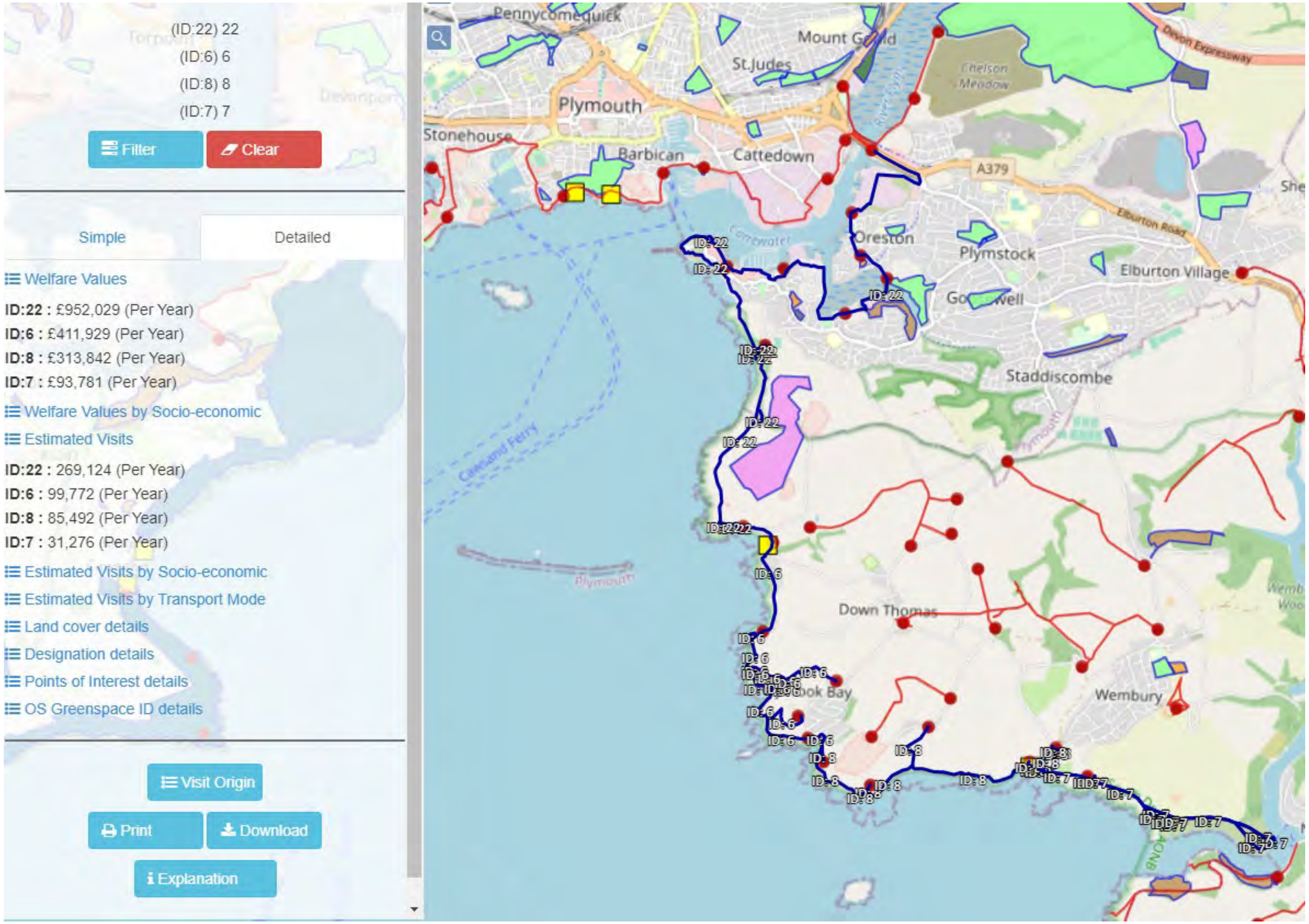
ID:152851 :
AB: 14,278 (Per Year)
C1: 26,177 (Per Year)
C2: 12,556 (Per Year)
DE: 12,410 (Per Year)

ID:152849 :
AB: 12,498 (Per Year)
C1: 23,827 (Per Year)
C2: 12,099 (Per Year)
DE: 12,233 (Per Year)

The city (the ferry to Laira bridge) – baseline – beaches (Plymouth Hoe West and Plymouth Hoe East, two points marked in blue at bottom below)



The coast path from Laira bridge round to the NMP Phase one boundary on the east of the city – baseline – coastal path (blue line)



Welfare values by socio-economic group:

ID:22 :
AB: £241,811 (Per Year)
C1: £343,291 (Per Year)
C2: £202,139 (Per Year)
DE: £164,789 (Per Year)

ID:6 :
AB: £106,567 (Per Year)
C1: £141,058 (Per Year)
C2: £90,879 (Per Year)
DE: £73,425 (Per Year)

ID:8 :
AB: £91,744 (Per Year)
C1: £106,406 (Per Year)
C2: £65,556 (Per Year)
DE: £50,136 (Per Year)

ID:7 :
AB: £29,312 (Per Year)
C1: £32,112 (Per Year)
C2: £18,340 (Per Year)
DE: £14,017 (Per Year)

Estimated visits by socio-economic group:

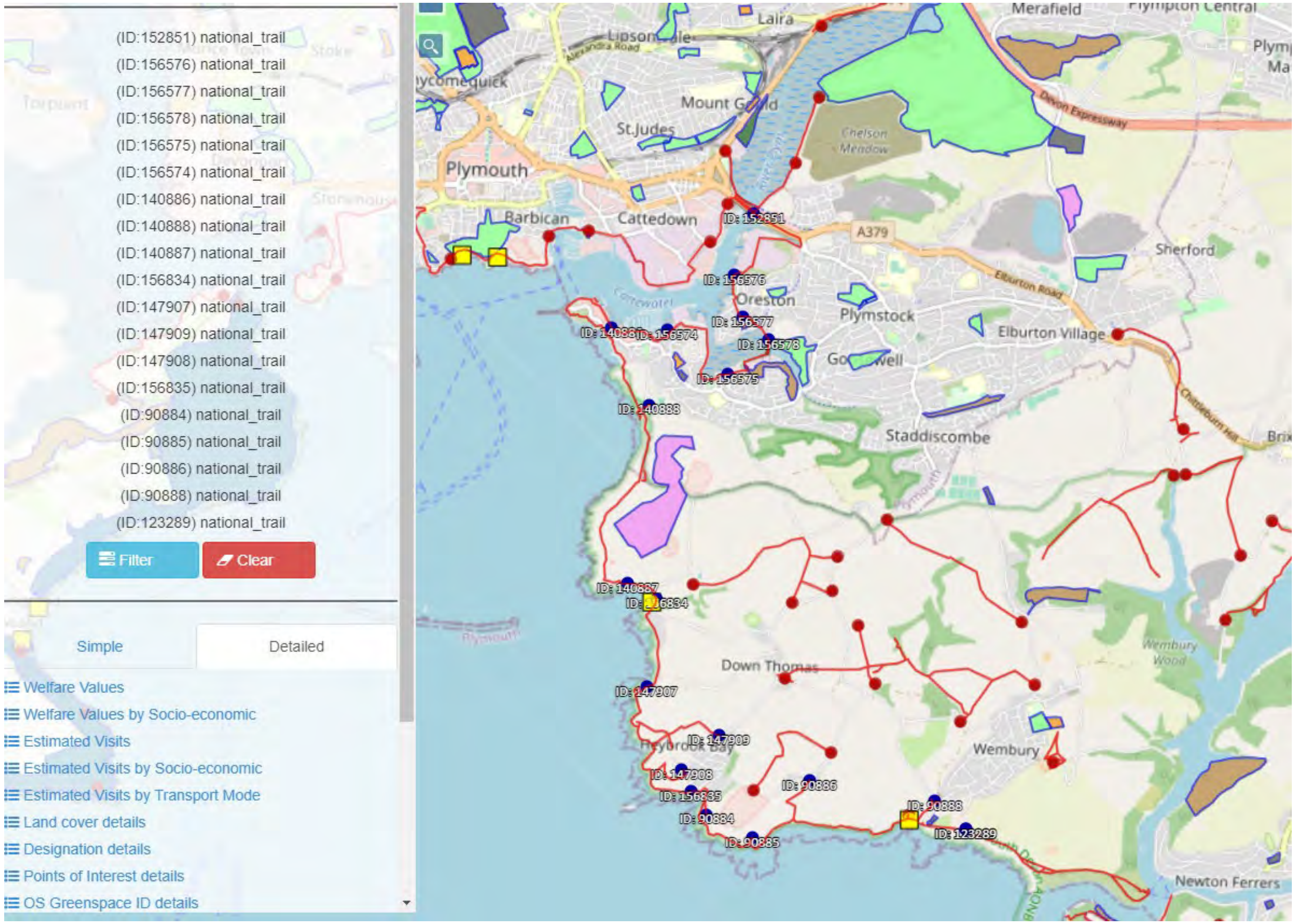
ID:22 :
AB: 69,445 (Per Year)
C1: 97,353 (Per Year)
C2: 56,691 (Per Year)
DE: 45,635 (Per Year)

ID:6 :
AB: 26,342 (Per Year)
C1: 34,273 (Per Year)
C2: 21,745 (Per Year)
DE: 17,411 (Per Year)

ID:8 :
AB: 26,385 (Per Year)
C1: 28,967 (Per Year)
C2: 17,296 (Per Year)
DE: 12,843 (Per Year)

ID:7 :
AB: 10,373 (Per Year)
C1: 10,706 (Per Year)
C2: 5,856 (Per Year)
DE: 4,341 (Per Year)

The coast path from Laira bridge round to the NMP Phase one boundary on the east of the city – baseline – access points (blue points)



Welfare values:

ID:152851 : £262,031 (Per Year)
ID:156576 : £169,194 (Per Year)
ID:156577 : £166,711 (Per Year)
ID:156578 : £157,230 (Per Year)
ID:156575 : £125,426 (Per Year)
ID:156574 : £97,772 (Per Year)
ID:140886 : £87,251 (Per Year)
ID:140888 : £91,491 (Per Year)
ID:140887 : £56,954 (Per Year)
ID:156834 : £71,833 (Per Year)
ID:147907 : £77,233 (Per Year)
ID:147909 : £97,193 (Per Year)
ID:147908 : £87,441 (Per Year)
ID:156835 : £78,229 (Per Year)
ID:90884 : £47,774 (Per Year)
ID:90885 : £42,534 (Per Year)
ID:90886 : £82,633 (Per Year)
ID:90888 : £72,972 (Per Year)
ID:123289 : £93,781 (Per Year)

Welfare values by socio-economic group:

ID:152851 :
AB: £58,008 (Per Year)
C1: £103,373 (Per Year)
C2: £51,070 (Per Year)
DE: £49,579 (Per Year)

ID:156576 :
AB: £40,533 (Per Year)
C1: £63,280 (Per Year)

C2: £34,900 (Per Year)
DE: £30,481 (Per Year)

ID:156577 :
AB: £40,569 (Per Year)
C1: £61,765 (Per Year)
C2: £34,715 (Per Year)
DE: £29,662 (Per Year)

ID:156578 :
AB: £38,903 (Per Year)
C1: £57,662 (Per Year)
C2: £33,062 (Per Year)
DE: £27,603 (Per Year)

ID:156575 :
AB: £33,749 (Per Year)
C1: £44,304 (Per Year)
C2: £26,912 (Per Year)
DE: £20,461 (Per Year)

ID:156574 :
AB: £26,171 (Per Year)
C1: £34,237 (Per Year)
C2: £21,101 (Per Year)
DE: £16,264 (Per Year)

ID:140886 :
AB: £23,171 (Per Year)
C1: £30,436 (Per Year)
C2: £18,917 (Per Year)
DE: £14,727 (Per Year)

ID:140888 :
AB: £24,347 (Per Year)
C1: £31,953 (Per Year)
C2: £19,831 (Per Year)
DE: £15,361 (Per Year)

ID:140887 :
AB: £14,370 (Per Year)
C1: £19,653 (Per Year)
C2: £12,700 (Per Year)
DE: £10,231 (Per Year)

ID:156834 :
AB: £17,717 (Per Year)
C1: £24,754 (Per Year)
C2: £16,053 (Per Year)
DE: £13,310 (Per Year)

ID:147907 :
AB: £19,341 (Per Year)
C1: £26,448 (Per Year)
C2: £17,265 (Per Year)
DE: £14,179 (Per Year)

ID:147909 :
AB: £26,223 (Per Year)
C1: £33,289 (Per Year)
C2: £21,122 (Per Year)
DE: £16,560 (Per Year)

ID:147908 :
AB: £23,082 (Per Year)

C1: £29,878 (Per Year)
C2: £19,160 (Per Year)
DE: £15,321 (Per Year)

ID:156835 :
AB: £20,204 (Per Year)
C1: £26,690 (Per Year)
C2: £17,279 (Per Year)
DE: £14,055 (Per Year)

ID:90884 :
AB: £13,879 (Per Year)
C1: £16,144 (Per Year)
C2: £10,040 (Per Year)
DE: £7,711 (Per Year)

ID:90885 :
AB: £12,177 (Per Year)
C1: £14,383 (Per Year)
C2: £8,991 (Per Year)
DE: £6,982 (Per Year)

ID:90886 :
AB: £25,202 (Per Year)
C1: £27,956 (Per Year)
C2: £17,006 (Per Year)
DE: £12,470 (Per Year)

ID:90888 :
AB: £21,121 (Per Year)
C1: £24,832 (Per Year)
C2: £15,238 (Per Year)
DE: £11,782 (Per Year)

ID:123289 :
AB: £29,312 (Per Year)
C1: £32,112 (Per Year)
C2: £18,340 (Per Year)
DE: £14,017 (Per Year)

Estimated visits:

ID:152851 : 65,420 (Per Year)
ID:156576 : 48,615 (Per Year)
ID:156577 : 48,138 (Per Year)
ID:156578 : 45,275 (Per Year)
ID:156575 : 36,994 (Per Year)
ID:156574 : 27,409 (Per Year)
ID:140886 : 23,731 (Per Year)
ID:140888 : 25,306 (Per Year)
ID:140887 : 13,655 (Per Year)
ID:156834 : 16,899 (Per Year)
ID:147907 : 18,082 (Per Year)
ID:147909 : 24,683 (Per Year)
ID:147908 : 21,451 (Per Year)
ID:156835 : 18,657 (Per Year)
ID:90884 : 12,702 (Per Year)
ID:90885 : 11,055 (Per Year)
ID:90886 : 24,204 (Per Year)
ID:90888 : 19,624 (Per Year)
ID:123289 : 31,276 (Per Year)

Estimated visits by socio-economic group:

ID:152851 :
AB: 14,278 (Per Year)

C1: 26,177 (Per Year)
C2: 12,556 (Per Year)
DE: 12,410 (Per Year)

ID:156576 :
AB: 11,760 (Per Year)
C1: 18,179 (Per Year)
C2: 10,007 (Per Year)
DE: 8,668 (Per Year)

ID:156577 :
AB: 11,864 (Per Year)
C1: 17,810 (Per Year)
C2: 10,013 (Per Year)
DE: 8,451 (Per Year)

ID:156578 :
AB: 11,376 (Per Year)
C1: 16,578 (Per Year)
C2: 9,509 (Per Year)
DE: 7,812 (Per Year)

ID:156575 :
AB: 10,157 (Per Year)
C1: 13,153 (Per Year)
C2: 7,835 (Per Year)
DE: 5,850 (Per Year)

ID:156574 :
AB: 7,505 (Per Year)
C1: 9,665 (Per Year)
C2: 5,825 (Per Year)
DE: 4,414 (Per Year)

ID:140886 :
AB: 6,440 (Per Year)
C1: 8,335 (Per Year)
C2: 5,070 (Per Year)
DE: 3,887 (Per Year)

ID:140888 :
AB: 6,885 (Per Year)
C1: 8,901 (Per Year)
C2: 5,403 (Per Year)
DE: 4,118 (Per Year)

ID:140887 :
AB: 3,458 (Per Year)
C1: 4,732 (Per Year)
C2: 3,029 (Per Year)
DE: 2,436 (Per Year)

ID:156834 :
AB: 4,169 (Per Year)
C1: 5,852 (Per Year)
C2: 3,756 (Per Year)
DE: 3,122 (Per Year)

ID:147907 :
AB: 4,536 (Per Year)
C1: 6,222 (Per Year)
C2: 4,020 (Per Year)
DE: 3,304 (Per Year)

ID:147909 :
AB: 6,917 (Per Year)

C1: 8,468 (Per Year)
C2: 5,263 (Per Year)
DE: 4,036 (Per Year)

ID:147908 :
AB: 5,822 (Per Year)
C1: 7,346 (Per Year)
C2: 4,630 (Per Year)
DE: 3,653 (Per Year)

ID:156835 :
AB: 4,897 (Per Year)
C1: 6,385 (Per Year)
C2: 4,077 (Per Year)
DE: 3,297 (Per Year)

ID:90884 :
AB: 3,901 (Per Year)
C1: 4,283 (Per Year)
C2: 2,592 (Per Year)
DE: 1,926 (Per Year)

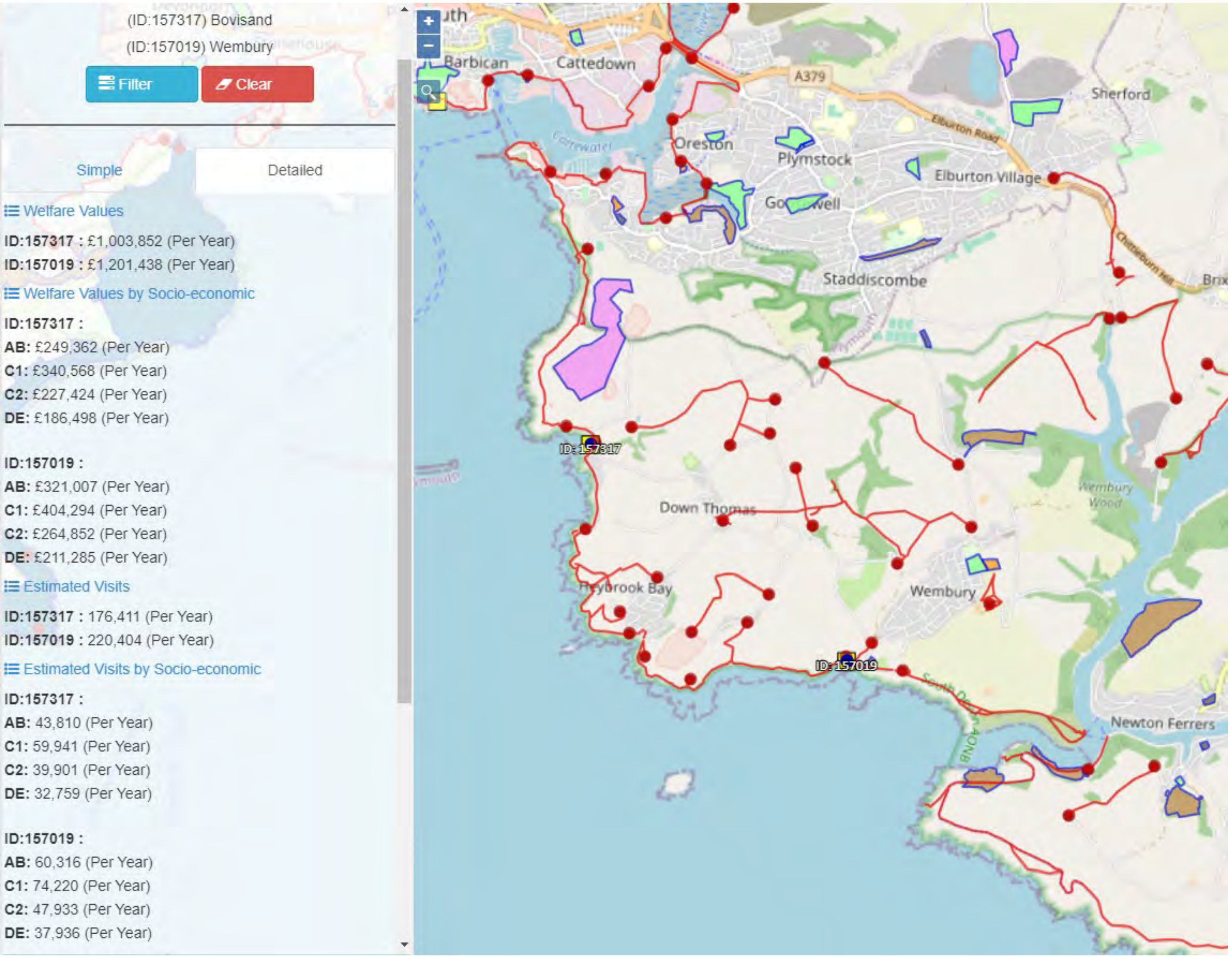
ID:90885 :
AB: 3,325 (Per Year)
C1: 3,734 (Per Year)
C2: 2,276 (Per Year)
DE: 1,720 (Per Year)

ID:90886 :
AB: 7,918 (Per Year)
C1: 8,153 (Per Year)
C2: 4,792 (Per Year)
DE: 3,340 (Per Year)

ID:90888 :
AB: 5,934 (Per Year)
C1: 6,693 (Per Year)
C2: 3,975 (Per Year)
DE: 3,023 (Per Year)

ID:123289 :
AB: 10,373 (Per Year)
C1: 10,706 (Per Year)
C2: 5,856 (Per Year)
DE: 4,341 (Per Year)

The coastal path from Laira bridge round to the NMP Phase one boundary on the east of the city – baseline – beaches



Population futures and Dartmoor National Park

Implications of development around the outskirts of Dartmoor for recreational use and management of access

EXTENDED SUMMARY

August 2018

Report to Dartmoor National Park Authority

Brett Day
Amii Harwood
Charles Tyler
Sara Zonneveld

THIS REPORT CONTAINS INFORMATION ON SENSITIVE SPECIES – PLEASE DO NOT DISTRIBUTE WITHOUT PERMISSION

Applying research to benefit our environment and economy

This is an extended summary of the report titled "Population futures and Dartmoor National Park – Implications of developments around the outskirts of Dartmoor for recreational use and management of access". To access information from the full report, please contact the Dartmoor National Park Authority.

A short executive summary can be found at the end of this summary report.

Acknowledgements:

The research in this report was funded by Dartmoor National Parks Authority and by the Natural Environment Research Council (NERC) through the SWEEP project.

We would like to thank all local species experts for sharing their knowledge on the local ecology and distribution of key species. The names of individuals who contributed by filling in key species questionnaires are listed in the full report.

1 INTRODUCTION

Dartmoor National Park is enjoyed by large numbers of visitors. Significant new housing developments and population growth in the districts around Dartmoor will inevitably result in increases in the number of visitors to the National Park. In order to ensure both high quality recreational experiences and successful environmental protection, there is a need to better understand how new housing developments will impact Dartmoor. In response to that challenge, the Dartmoor National Park Authority (DNPA) outlined the following key questions for which answers were needed:

- Where do visitors currently come from?
- How will housing levels change in the areas around the National Park?
- How may visitor numbers, visitor distribution and types of access change?
- What are the impacts from National Park access and how important are those impacts?
- What needs to be done in terms of mitigation or changes to access management to provide for the changes forecast?

This report, compiled by staff of the SWEEP partnership (www.sweep.ac.uk) at the University of Exeter, sets out to provide answers to those questions.

In achieving that goal the research team have drawn on numerous information sources bringing together secondary data, modelling capacity and drawing on expert inputs in order to present a comprehensive assessment of the impacts on Dartmoor of future population increases.

2 POPULATION FUTURES

Using Office of National Statistics (ONS) population projections augmented by details of proposed property developments described in Local Plans, we construct spatial projections of population change in order to be able to assess the future impacts of recreation on Dartmoor National Park. Due to their connectivity to Dartmoor National Park, our analysis focuses primarily on eight local government areas that define Dartmoor's hinterland, referred to as Local Authority Districts or LADs. These are: West Devon, Teignbridge, South Hams, Exeter, Plymouth, Torbay, Mid-Devon and East Devon.

ONS population projections show that over the 25 years from 2014 to 2039, the overall population in the region is projected to increase by 13% from around 1 million people in mid-2014 to 1.1 million in mid-2039, with differences in population growth between the different LADs. The information on ONS population predictions is then brought together with the details from local plans to provide a spatialized prediction on local population growth. Figure 1 summarises the overall change, mapping out the predicted population changes between 2014 and 2039 in the eight LADs of the Dartmoor hinterland. For full details and methodology, please refer to the full report.

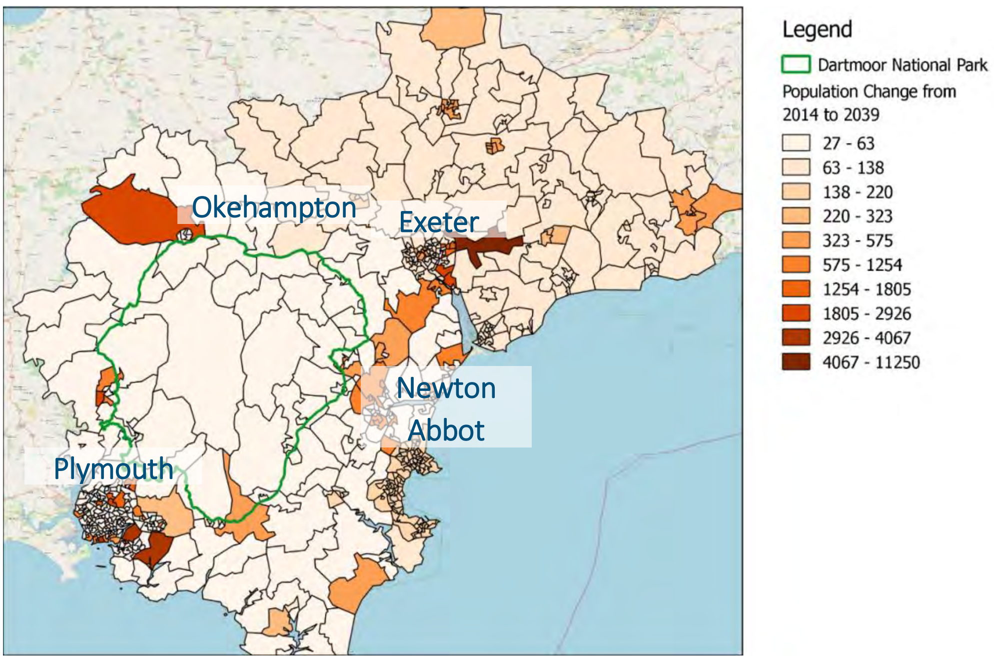


Figure 1: Projected population increases from 2014 to 2039 by LSOA

3 RECREATION FUTURES

3.1 THE ORVAL MODEL

Understanding the likely impacts of the future population changes described in Section 2 requires making forecasts about footfall. In this project our approach to forecasting is to use models based on empirical data describing currently observed behaviour, and use that to predict how future populations might be expected to behave. The core modelling tool used in our analysis is the Outdoor Recreation Valuation (ORVal) model, developed by the LEEP Institute in the University of Exeter. The ORVal model is a statistical recreation demand model that can be used to predict the number of day visits that are made by adult residents of England to different outdoor greenspaces. The model adjusts its predictions according to a number of factors, most particularly the socioeconomic characteristics of people, the day of the week, the month of the year, the attributes of a greenspace and the availability and qualities of alternative greenspaces.

In this project we use the ORVal model to predict visits to Dartmoor. The model allows us to disaggregate those predictions in a number of ways. In particular, we can disaggregate them by home location in order to examine the contribution to visits made by residents of the eight LADs in the Dartmoor hinterland. We can make predictions as to how many of those trips are made by car as opposed to on foot. Moreover, we can disaggregate trips by the locations on Dartmoor at which visitors begin their recreational activity in order to understand how recreational activity is distributed across the National Park. For full details on the ORVal model and methodology please refer to the full report or Day and Smith (2018).

Applying the model to the 2014 population estimates allows us to provide estimates of visits to Dartmoor. We calculate an estimate of 7.8 million annual visits to the National Park. The majority of these day visits (92%) come from the 8 neighbouring LADs, the remainder from the rest of England. Of all trips, 30% are "new" outdoor recreation visits (where the individual would not have taken an outdoor recreation trip instead of the trip to Dartmoor).

Most importantly for our purposes, the calibrated ORVal model allows us to make predictions regarding visits from the expanding populations of the 8 neighbouring

LADs (see Table 1). We can see that the increasing populations in those LADs will result in the number of visits growing from an estimated 7,110,903 in 2014 to an estimated 7,983,217 in 2039, a growth of 12.3%.

Table 1: Growth in predicted visits to Dartmoor National Park 2014-39

LAD	2014	2019	2024	2029	2034	2039	Change 2014-39
East Devon	210,908	224,005	240,233	256,727	271,443	278,587	32.1%
Exeter	429,031	446,877	459,191	477,393	492,139	506,672	18.1%
Teignbridge	1,899,369	1,937,994	1,983,966	2,033,513	2,078,499	2,136,734	12.5%
West Devon	1,500,946	1,560,296	1,577,714	1,599,585	1,617,671	1,650,840	10.0%
Mid Devon	230,784	234,852	239,714	244,713	251,192	257,132	11.4%
Torbay	473,268	481,883	494,208	508,203	521,194	533,101	12.6%
Plymouth	1,374,116	1,413,406	1,438,915	1,476,701	1,506,000	1,532,663	11.5%
South Hams	992,481	1,015,249	1,029,116	1,050,436	1,067,131	1,087,488	9.6%
Total:	7,110,903	7,314,562	7,463,057	7,647,271	7,805,269	7,983,217	12.3%

3.2 PREDICTING RECREATIONAL ACTIVITY ACROSS DARTMOOR

While the ORVal model provides us with an insight into the distribution of visits across Dartmoor, it does not tell us anything about their subsequent activities. Insights on this can be obtained from the Monitor of Engagement with the Natural Environment (MENE), a survey of recreation day visits taken by English residents to the upland national parks of England. From the MENE survey we know that 81% of visitors come to Dartmoor for roaming recreation (e.g. walking, biking, horse-riding). The remaining 19% visits for activity-focused recreation, where individuals travel to a particular destination to undertake an activity such as fishing, eating out or visiting an attraction, as well as “other” unspecified activities. By far the most popular recreation type is “walking or running”, with 78% of all visitors visiting Dartmoor for this reason. When predicting future recreational activities across Dartmoor, we make the assumption that the patterns of activity in the future will remain similar to those suggested by the MENE data.

In order to translate predictions of visits to National Park access points into measures of intensity of use of the Dartmoor landscape we developed predictions of where and how far visitors travel through that landscape. This is done separately for roaming recreation and activity-focused recreation. For roaming recreation, we assume a Gaussian distribution, a statistical distribution which captures the fact that most visitors walk average distances (of around 9km), and increasingly smaller proportions of visitors taking longer and shorter walks. For activity-focused recreation we use an exponential function, assuming most people will transport themselves to an access point in proximity of the location in which they wish to undertake their leisure activity (median walking distance +-2km), with fewer individuals walking longer distances to reach the location of their activity. Using this information on walking distances, we can then build up estimates of the intensity of use of different locations across the Dartmoor landscape. Since our eventual focus will concern possible levels of disturbance caused by recreation on Dartmoor, we choose to illustrate footfall intensity by examining activity on the busiest days of the year. To that end we extract the ORVal visit predictions for a peak hour during a weekend day in the height of summer.

Figure 2 provides an illustration of footfall intensity estimates made for the 2019 population predictions at a time of peak activity on a summer weekend.

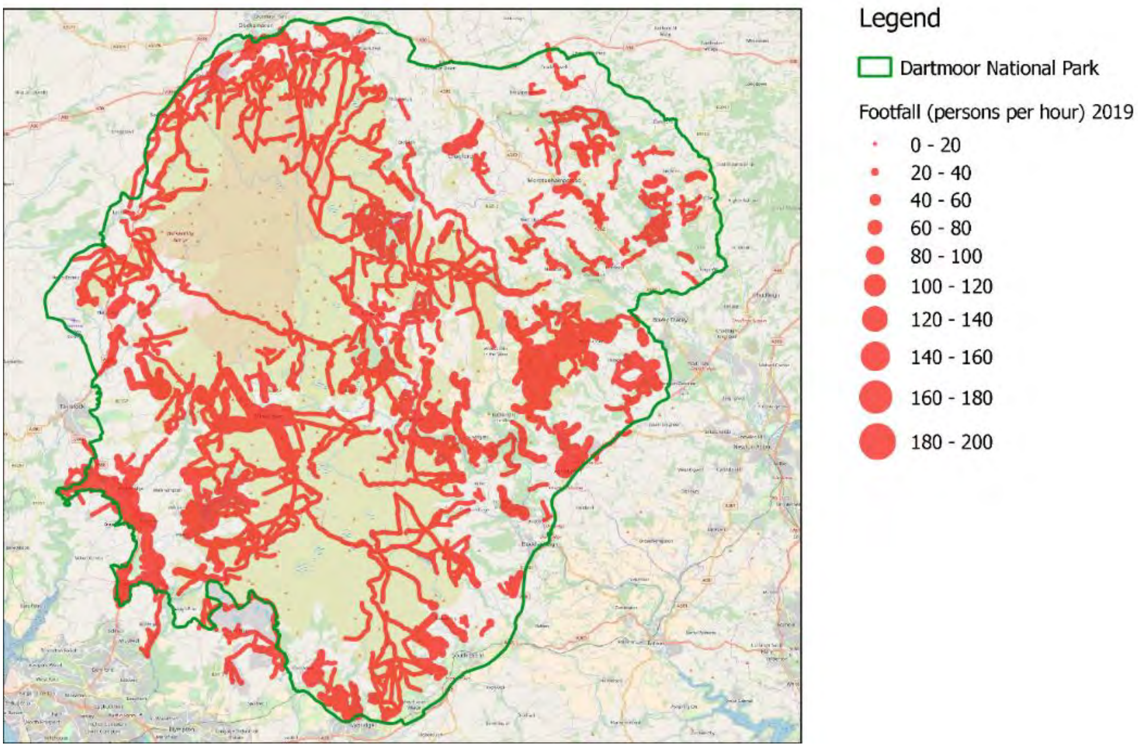


Figure 2. Predictions of peak hourly (summer weekend) footfall across Dartmoor in 2019.

While it is difficult to summarise the detail of these spatialized predictions, it is clear from Figure 2 that a number of high intensity footfall areas exist across the National Park. For example, areas which stand out are those around Haytor, Princetown and

Burrator, though other areas of intensive use are also evident. Applying the same methods to the populations expected in future years allows us to make predictions as to how footfall intensity might increase across the National Park over time. Those predictions of growth in footfall are illustrated in Figure 3. Please note that the scale of the size of symbols for illustrated footfall has changed from that in Figure 2 which shows absolute levels in 2019.

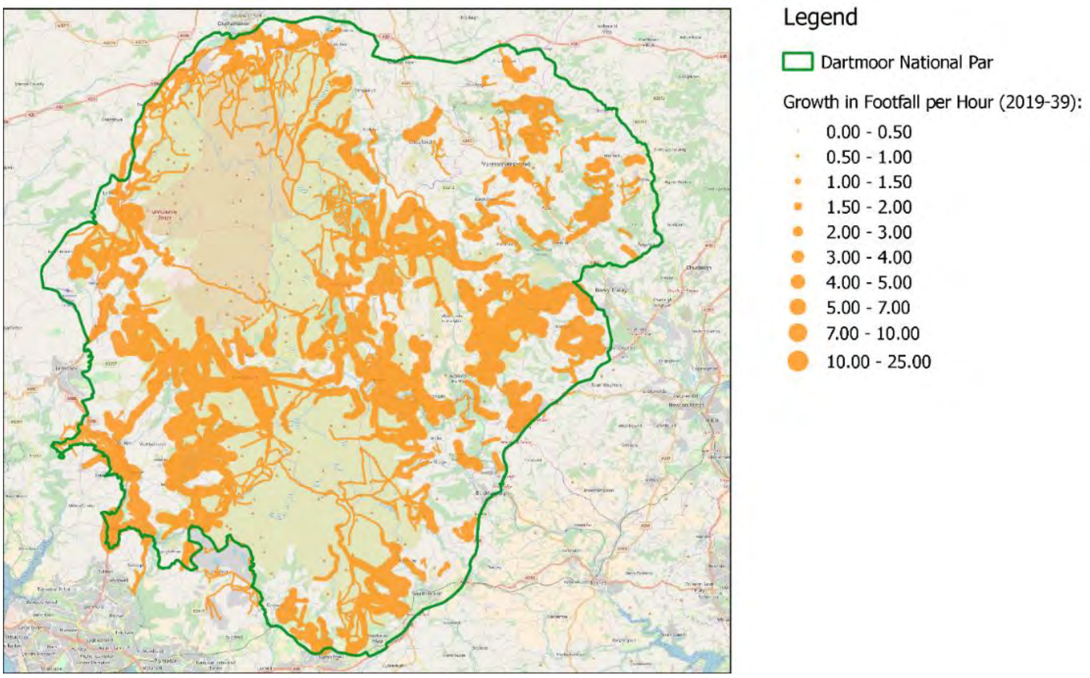


Figure 3. Growth in footfall (increase in persons per hour at peak times) across Dartmoor from 2019 to 2039.

From Figure 3 it is clear that fairly substantial increases in footfall intensity are expected in several locations across the National Park with peak increases of around 25 persons per hour at peak times. Not surprisingly, the locations attracting the largest increases in footfall are those that are also currently most attractive to visitors. The prediction algorithms also allow us to disaggregate the growth in footfall intensity by the local authority area from which visits arose. From such analysis it can be seen that growth in footfall tends to be greatest in areas within the National Park that fall within or near the corresponding LAD, with for example Teignbridge predominantly contributing to the footfall growth in the east of Dartmoor, and Plymouth to the southwest of Dartmoor. For LADs stretching further away from Dartmoor, such as East Devon and Mid Devon, growth in footfall is more evenly spread across the National Park. Maps of footfall disaggregated by LAD are available in the full version of this report

4 BENEFITS OF DARTMOOR

4.1 WELFARE BENEFITS

In social cost-benefit analysis (as prescribed, for example, in the Treasury Greenbook) enjoyment can be quantified by translating it into a measure of Willingness to Pay (WTP), a measure of welfare. In this context, WTP measures the maximum amount of money that an individual would be prepared to give up in order to ensure that they could visit a recreation site on Dartmoor. The ORVal model (discussed above) can be used to calculate the WTP of each adult in England for each recreation site on Dartmoor.

Table 2 provides estimates of current and predicted future welfare benefits derived from recreational use of Dartmoor for the residents of each of the eight LADs. The headline figures are that Dartmoor currently provides an estimated £25.6 million of welfare benefits to the residents of the 8 neighbouring LADs each year. By 2039, this is predicted to rise from to £28.1 million; an increase of annual welfare benefit of £2.5 million. Detailed information on the principles and methodology behind the WTP methodology, and on the welfare generated by Dartmoor recreation disaggregated by socioeconomic segment are given in the full report.

Table 2: Welfare predictions for Dartmoor recreation day visits from neighbouring Local Authority Districts for 2019 population estimates

Region	2019 Welfare (£2016)		2039 Welfare (£2016)		Change in annual Welfare 2019-39 (£2016)
	Total	Per Head	Total	Per Head	
East Devon	970,758	8.18	1,200,070	8.77	229,313
Exeter	1,807,818	16.60	2,051,361	16.61	243,543
Teignbridge	6,417,551	58.43	7,116,188	56.97	698,637
West Devon	4,728,658	95.59	5,025,164	93.10	296,506
Mid Devon	928,539	14.03	1,017,552	13.84	89,013
Torbay	2,050,026	18.17	2,267,994	18.17	217,968
Plymouth	5,351,929	24.10	5,803,982	23.99	452,053
South Hams	3,376,965	46.41	3,631,514	45.96	254,548
Total:	25,634,263		28,115,865		2,481,582

4.2 ACTIVITY BENEFITS

Another benefit provided by the National Park arises from the potential health gains of that recreational activity carried out on Dartmoor. Our analysis of footfall allows us to predict the sum of distance walked by all visitors and for those from each neighbouring LAD (Table 3). Using existing data on average stride length and energy expenditure we then estimate energy useage and fat burn by Dartmoor visitors. The headline figures from Table 3 are that access Dartmoor facilitates recreational activity that results in the visiting population of England burning an estimated 129,030 kg of fat each year. Just under 100,000 kg of that fat-burn is realised by residents of the local LADs.

Table 3. Aggregate physical activity levels from predicted recreational activity on Dartmoor in 2019

Region	Distance (km)	Steps (million)	Energy Expenditure (kJ)	Fat Burned (kg)
England	18,376,854	24,502	4,774,098,770	129,030
East Devon	304,121	405	79,007,079	2,135
Exeter	694,528	926	180,430,554	4,877
Teignbridge	3,267,405	4,357	848,834,744	22,941
West Devon	3,579,904	4,773	930,018,622	25,136
Mid Devon	301,920	403	78,435,513	2,120
Torbay	827,370	1,103	214,941,293	5,809
City of Plymouth	3,580,704	4,774	930,226,352	25,141
South Hams	1,686,138	2,248	438,039,519	11,839

One thing to note about the figures in Table 3 is that we cannot assume that without Dartmoor the physical activity would not instead have been undertaken at some other outdoor recreation site. One reasonably defensible assumption is that the physical activity benefits of trips to Dartmoor that are ‘new’ (i.e. where the individual would not have taken an outdoor recreation trip instead of the trip to Dartmoor) are wholly attributable to the existence of the recreation facilities of the National Park. From our ORVal estimates we know the number of new visits to be around 30% of total visits (see section 3), such that a good lower bound estimate of physical activity benefits would be 30% of the figures in Table 3.

5 COSTS TO DARTMOOR

5.1 PATH EROSION

Increased footfall on Dartmoor has the potential to contribute to increased levels of path erosion and soil compaction. We used data from Coleman (1981), which provides a comprehensive assessment of factors impacting on footpath erosion in the Lake District, to make predictions regarding rates of path erosion on Dartmoor. The results of that analysis are visualised in Figure 4. Erosion risk is focused on steep paths particularly in those areas experiencing the most predicted footfall. We calculated that by 2039 rising visitation might be responsible for an additional 74,135m^3 of vegetation being damaged from recreation pressure widening footpaths. Moreover, an additional 10,854 m^2 of bare ground might be exposed along the path network. Some 250m of path will experience increased gullying in excess of 5cm depth and 42km of path will experience gullying of more than 1cm. While a Dartmoor-specific primary study would likely be needed to more clearly define the nature of erosion problems across the National Park, the analysis suggests that the magnitude of visitation increase will likely have impacts across wide areas on trampling of vegetation with substantial more localised erosion of paths particularly on steep sections of paths.

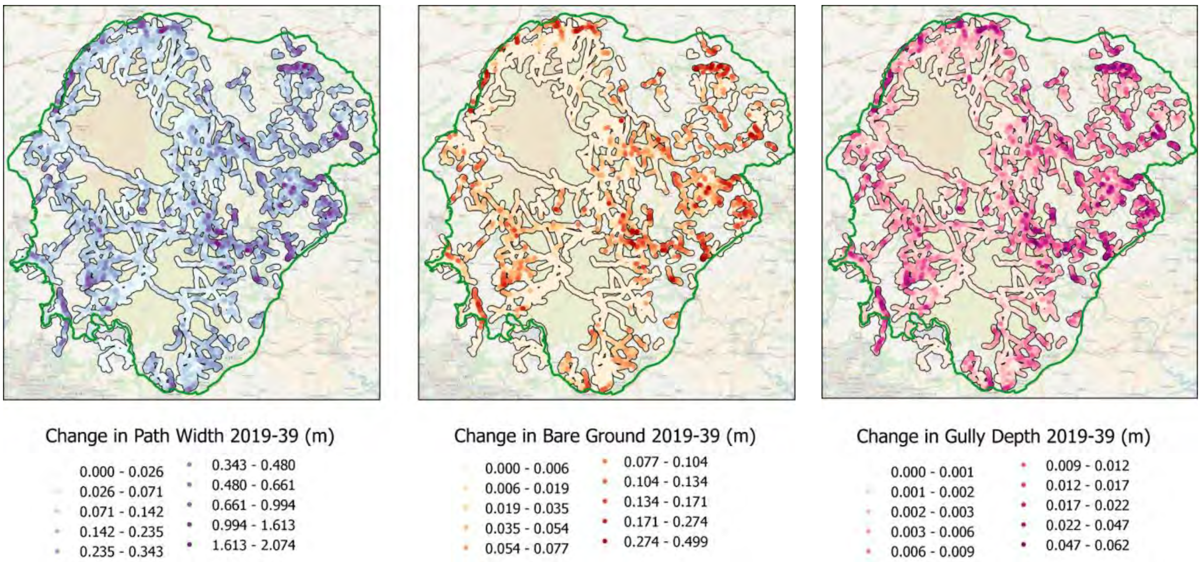


Figure 4. Predictions of locations of increasing erosion by 2039

5.2 WILDLIFE DISTURBANCE

To evaluate the potential impacts of recreation on Dartmoor wildlife, we reviewed the existing scientific literature and carried out analyses based on questionnaires with local species experts. An overview of findings and suggested mitigation measures from the scientific literature can be found in the full report. The species questionnaires aimed to understand the local requirements, distribution and sensitivity to a range of recreational activities for key Dartmoor species. Key species were selected from two local publications; the State of Dartmoor's Key Wildlife, and the Devon Special Species List. The selected species have local, national or international importance, and represent a broad range of habitats and species groups.

Questionnaires and species impact case studies were completed for: *Adder, Blue Ground Beetle, Bog Hoverfly, Cuckoo, Dartford Warbler, Dipper , Dunlin, Fairy Shrimp, Greater Horseshoe Bat, Hen Harrier, High Brown Fritillary, Marsh Fritillary, Narrow-bordered Bee Hawkmoth, Nightjar, Otter, Pearl-bordered Fritillary, Peregrine Falcon, Plants* (generic overview across lower and higher plants)*, Raven, Red Grouse, Ring Ouzel, Salmon, Skylark, Snipe, Southern Damselfly, Whinchat and Wood Warbler.*

Full species case studies and hotspot maps are excluded from this summary report due to the sensitivities of releasing such information for some species. An overview of findings is provided in Table 4.

Table 4. Activity types and impacted key species

Activity type	Affected key species

Walking/ hiking/ running	• Butterflies & moths
	  ▪ low levels of disturbance to individuals
	  ▪ trampling of key vegetation or food plants under high footfall
	• **Cuckoo** (disturbance to breeding behaviour and fledglings)
	• **Dartford Warbler** (reduced breeding performance)
	• **Dunlin** (potential disturbance but currently low spatial overlap with recreation)
	• **Nightjar** (disturbance leading to nest failure)
	• **Plants** (trampling damage)
	• **Raven** (potential future breeding disturbance)
	• **Ring Ouzel** (disturbance and nest failure)
	• **Whinchat** (breeding disturbance)
	• **Wood Warbler** (disturbance to territory settlement and breeding)

Activity type	Affected key species
Large events	• **Adder** (disturbance to breeding areas) • **Butterflies & moths** (trampling of key vegetation or foodplants) • **Cuckoo** (prolonged disturbance & displacement of birds from sites) • **Dartford Warbler** (prolonged disturbance) • **Dunlin** (prolonged disturbance) • **Plants** (trampling damage) • **Red Grouse** (prolonged disturbance) • **Ring Ouzel** (prolonged disturbance) • **Skylark** (increased trampling risk due to nests in open vegetation) • **Southern Damselfly** (trampling of key habitat) • **Wood Warbler** (breeding disturbance and trampling risk)
Dog-walking	Effects similar to walking with additional negative effects,, e.g: • **Adder** (disturbance) • **Cuckoo** (disturbance to breeding behaviour and fledglings) • **Ground-nesting birds** (generally more easily disturbed by dogs than by humans only, increased flushing at nests can lead to increased predation risk) • **Plants** (potential nutrification)
Mountain-biking	• **Nightjar** (disturbance from off-road cycling in conifer plantations) • **Plants** ("trampling" damage) • **Wood Warbler** (potential breeding disturbance)
Horse-riding	• **Plants** (trampling damage)
Increased car traffic	• **Adder** (occasional collision death) • **Butterflies & moths** (occasional collision death) • **Cuckoo** (occasional collision death) • **Greater Horseshoe Bat** (collision death, disturbance to commuting from lights at night) • **Otter** (occasional collision death) • **Plants** (possible indirect effects due to reduced air quality)
Wildlife watching/ naturalists	• **Butterflies & moths** (illegal collection) • **Hen Harrier** (disturbance of roost sites by birdwatchers) • **Ring Ouzel** (disturbance and nest site trampling can lead to displacement and reduced breeding success) • **Wood Warbler** (prolonged breeding disturbance due to information-sharing between photographers)
Fire/arson	• Butterflies & moths (habitat loss) • **Plants** (vegetation loss)
Camping/ barbecues/ picnics	Causes prolonged disturbance and/or displacement, such as: • Most **breeding birds** when activity takes place in/near territory
Kayaking/ swimming/ fishing	• **Dipper** (potential disturbance to territorial behaviour, foraging behaviour and fledglings) • **Plants** (loss of lower plants from stones at access points, trampling)

Activity type	Affected key species
	• **Salmon** (exploitation from illegal fishing, potential disturbance from dams created by visitors)
Caving	• **Greater Horseshoe Bat** (disturbance if roosting or hibernating in caves)
Climbing/ bouldering	• **Peregrine Falcon** (reduced breeding success) • **Raven** (breeding disturbance) • **Ring Ouzel** (potential for future disturbance at breeding sites)
Illegal raves	General disturbance to wildlife, e.g. Nightjar
Letterboxing/ geocaching	• **Plants** (loss of lower plants from stones) • **Ring Ouzel** (prolonged disturbance)
Joy-riding (off-road vehicles)	• **Southern Damselfly** (damage to key habitat)

Based on the questionnaire results, we assigned the key species into three levels of sensitivity to recreation activities, using the following categories:

Green: recreation impact unlikely. Species are either:

- not likely to be affected by any of the listed recreational activities, or
- spatial overlap between recreation and species occurrence is minimal, therefore substantial conflict is unlikely

Orange: recreation impact possible or minor

- Minor or localised recreation impacts could be a concern
- Strong effects unlikely (unless there are major changes in recreation patterns)

Red: recreation impact high or likely

- Adverse impacts have been recorded
- Spatial conflict and recreational impacts deemed likely

The sensitivity categories for each species are shown below. Sensitivity colours are assigned in the context of the current status of the species on Dartmoor, and the level of recreational use currently seen and realistically expected in the future for Dartmoor. These groupings are therefore specific to Dartmoor, would need to be reviewed periodically when recreational patterns or species distributions change, and would not necessarily be applicable to other locations.

Green: Blue Ground Beetle, Bog Hoverfly, Fairy Shrimp, Otter, Peregrine Falcon, Snipe
Orange: Adder, Hen Harrier, High Brown Fritillary, Marsh Fritillary, Narrow-Bordered Bee Hawkmoth, Pearl-Bordered Fritillary, Plants, Salmon, Skylark, Southern Damselfly

Red: Cuckoo, Dartford Warbler, Dipper, Dunlin, Greater Horseshoe Bat, Nightjar, Raven, Red Grouse, Ring Ouzel, Whinchat, Wood Warbler

For the species deemed sensitive to recreation impacts based on expert opinion (listed as "red" above),we used our data on predicted footfall data to map the likelihood of recreation impacts in future years. Hotspot and/or distribution information was not available for all species, and this mapping was therefore conducted only for Ring Ouzel, Red Grouse, Dunlin, Greater Horseshoe bat, Dipper, Wood Warbler, Nightjar and Cuckoo. A combined map of hotspots for these species and areas of growth in footfall is shown in Figure 5, illustrating areas where key species and recreation are predicted to come into increased conflict.

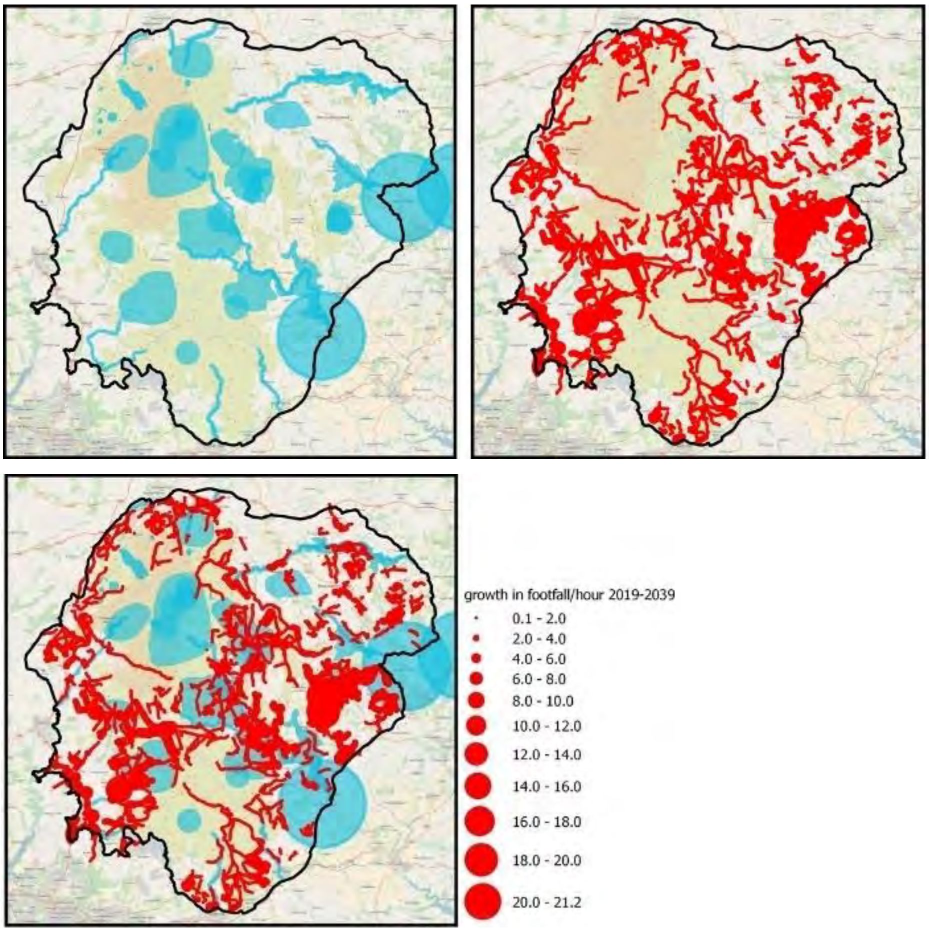


Figure 5. Key species hotspots (Cuckoo, Dipper, Greater Horseshoe Bat, Nightjar, Raven, Red Grouse, Ring Ouzel and Wood Warbler) (top left), predicted growth in footfall per hour 2019-39 (top right), and combined (bottom panel)

Based on Figure 5, we highlight 4 vulnerable wildlife locations where particularly strong increases in footfall are expected between now and 2039; the areas around Burrator, Dart Valley/Venford Reservoir, Haytor and Warren House/Soussons/ Fernworthy.

Our analysis from the ORVal model showed that visitors from a given LAD tend to focus trips to areas in the National Park that are closest to their location of residence. To understand from where the visitor growth in the four vulnerable areas will originate, the growth in footfall was mapped separately for each LAD. Findings are discussed below and associated maps are given in the full version of this report.

- **Burrator area**: The growth in footfall around this area is predicted to originate almost exclusively from the Plymouth, West Devon and the South Hams LADs. The highest increase in footfall is expected from the Plymouth area.
- **Dart Valley and Venford Reservoir**): The largest increase in footfall is predicted to come from the Teignbridge local authority area, with the Exeter, East Devon, Torbay, South Hams and Plymouth LADs also showing substantial growth in footfall across much of the Dart Valley and Venford Reservoir area.
- **Haytor area**: Increases in footfall around Haytor are predicted to originate from all local authority areas. The figure shows that visitors from the Teignbridge area are making the largest contribution to this growth
- **Warren House/Soussons/Fernworthy**: The total predicted hourly growth in footfall in this area appears to consist of visitor growth originating from all local authority areas, which is perhaps unsurprising given the central Dartmoor location of the Warren House/Soussons/Fernworthy area.

The vulnerable areas described above are examples only; wildlife and increased footfall may come into conflict at numerous other sites, also for species which were not investigated in this study. Furthermore, based on this information, precise effects of increased footfall on these species cannot be predicted. Threshold levels of footfall, above which negative effects occur, are largely unknown, and will differ between species, time of year, and other factors such as vegetation type or site geography. Detailed studies would be needed to derive species-specific recommendations on harmful footfall levels, but the information here can nonetheless be used to inform basic management decisions. For example, mitigation can be prioritised in the indicated vulnerable areas, as larger changes can be expected on those sites compared to other areas of Dartmoor.

5.3 MITIGATION MEASURES

Recommendations for potential measures for mitigating the impacts on wildlife are briefly listed below.

Several existing mitigation measures which are currently used by DNPA were listed by species experts as desirable. These include the existing policy around discouraging access to rare bird nesting area, prevention of illegal raves, and the policy of keeping details of nesting and/or roosting locations of rare birds (such as Hen Harrier) out of the public domain. The regulation of large events was also identified as an important policy; several bird species experts expressed serious concerns over the possible impacts on breeding birds resulting from the prolonged disturbance arising from such events. Both the consulted Dartmoor species experts and the information from the reviewed scientific literature highlight "dogs on leads" policies as an important mitigation measure. A "dogs on leads" policy is already in existence and can benefit a wide range of ground-nesting bird species, as well as minimising dog-Adder conflict, and the evidence, albeit limited, supports the continuation and possible extension (and further efforts for reinforcement) of this policy.

A number of targeted, smaller scale interventions were suggested which would be relatively straightforward to implement and are likely to benefit a number of key species. This includes the installation of Dipper nestboxes, an outreach initiative to educate the public on wildlife disturbance, and the use of temporary path closures to reduce footfall in sensitive areas.

In addition to the targeted mitigation measures outlined above, wider habitat management is key in providing sufficient suitable habitats for wildlife. Habitat enhancement or habitat creation can be used in strategic locations away from recreation hotspots in order to maximise the availability of habitat for key species. More generally, encouraging a rich diversity of vegetation types across the moor will ensure the availability of suitable habitat for a wide range of species. For example, avoiding burning in selected patches can create a mosaic of higher shrubbery to support a range of invertebrates and birds. Where used in targeted locations, this could also help reduce habitat penetrability for dogs and humans, and can therefore be used strategically to discourage recreational activity and prevent footpath creation or footpath widening in areas of concern.

A further broad mitigation measure is the active creation of "wildlife refuge areas" where recreation is discouraged. Temporary path closures can be used to prevent visitors entering sites where vulnerable species are found. However, full access restrictions are often not a feasible management option, and a range of alternative techniques can be used to discourage visitation to particular areas. As mentioned above, using patches of higher vegetation around key wildlife sites can reduce visitor numbers by reducing the accessibility of sites. Reduction (or prevention of expansion) of parking availability, and the provision of alternative access points can have similar effects. Signposting along access points and footpaths can be used to encourage visitors to take specific routes, thereby taking a land-sparing approach to recreational activities. The active creation of such "wildlife refuge areas" is not recommended to be necessary on the high open moors, which are natural refuges due to their inaccessibility and subsequent low levels of footfall. Areas which may be particularly suitable for the interventions outlined above are sites which are important for wildlife whilst not showing high predicted levels of increased footfall. Examples include the Tavy Teign and Bovey Valleys. On key conflict sites such as Warren House and Venford/Dart Valley, vegetation management and signposting could be used to encourage visitors towards certain areas whilst maintaining local wildlife refuges in these areas. A big honeypot site such as Haytor, which is predicted to experience large increases in visitor numbers over coming decades, may be a site of choice for the encouragement of recreation through promotion and the provision of additional access and facilities to draw visitors to this area, thereby sparing other sites. This can of course be combined with further access management (e.g. higher vegetation, footpath closures) at this site in order to discourage visitors from straying into nearby areas of conservation importance.

A number of the mitigation measures outlined above are currently being considered and/or implemented as part of the National Park's recreation strategy.

In addition to this report, an accompanying assessment on planning and legal systems was conducted in order to identify potential alternative income streams to fund mitigation measures. Further details can be found in the assessment report by Green Balance and Kristina Kenworthy.[1]

---

[1] Planning and legal advice – informing assessment of recreational impacts on Dartmoor National Park. Green Balance and Kristina Kenworthy. March 2018.

REFERENCES

Coleman, R., (1981). Footpath erosion in the English Lake District. *Applied Geography*, 1(2), pp. 121-131.

Davies, N, (2016). *Investigating route-choice by recreational walkers in the English Lake District*, A thesis submitted in partial fulfilment for the requirements for the degree of Doctor of Philosophy, at the University of Central Lancashire.

Day, B. H., and G. Smith (2016). Outdoor Recreation Valuation (ORVal) Data Set Construction. *Report to the Department of Food and Rural Affairs*.

Day, B. H., and G. Smith (2018). The Orval Recreation Demand Model. *Report to the Department of Food and Rural Affairs*.

ONS (2011) Output Area to Lower Layer Super Output Area to Middle Layer Super Output Area to Local Authority District (December 2011) Lookup in England and Wales. Office for National Statistics. DATASET. Available online: http://geoportal.statistics.gov.uk/datasets?q=OA_LSOA_MSOA_2011_LU&sort=name

ONS (2014) *SNPP Z1: 2014-based Subnational Population Projections.* Local Authorities in England, mid-2014 to mid-2039. DATASET and REPORT. Available online: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/subnationalpopulationprojectionsforengland/2014basedprojections

Executive Summary

- Dartmoor National Park is enjoyed by large numbers of visitors. Significant new housing developments and population growth in the districts around Dartmoor will inevitably result in increases in the number of visitors to the National Park.
- The statutory purposes for National Parks (Environment Act 1995) are to i) "*conserve and enhance the natural beauty, wildlife and cultural heritage*" and ii) "*promote opportunities for the understanding and enjoyment of the special qualities of national parks by the public*".
- In connection with these statutory purposes, the aim of this report is to identify both how the expanding population of Dartmoor's hinterland will benefit from the National Park as a recreational resource and also how the pressure of the additional visits coming from those new residents will impact on the National Park's environment.
- The report is compiled by academics from the SWEEP project (www.sweep.ac.uk) at the University of Exeter, and draws on secondary data, modelling capacity and on expert inputs in order to present a comprehensive assessment of the recreational future of Dartmoor..
- The first major contribution of this report is to construct spatialized predictions of population change in the Dartmoor hinterland from 2014 to 2039. Those predictions draw on Office of National Statistics population projections augmented by details of proposed property developments described in the Local Plans of the eight Local Authority Districts (LADs) that surround the National Park.
- To understand how new residents of the region might use Dartmoor, the spatialised population projections have been coupled with the Outdoor Recreation Valuation (ORVal) tool. ORVal is a sophisticated recreation demand model developed by the LEEP institute at the University of Exeter. As part of this project a bespoke calibration of the ORVal tool was developed and used to predict current and future patterns of visits to the array of recreation sites across Dartmoor National Park.
- The model indicates that Dartmoor is currently the backdrop for over 7 million day trips per year from residents of the eight neighbouring LADs. Moreover, increased populations in those LADs will result in more than 870,000 additional annual visits to Dartmoor per year, a rise of some 12%.
- The report also describes the development of a second bespoke modelling tool that extends the ORVal estimates of visitation into estimates of intensity of footfall through the National Park. That model used evidence from various

sources to approximate how far visitors might travel through the paths network during their visits. The resulting estimates of the spatial dispersion of visitors and the intensity of footfall across the National Park allows us to address a number of questions regarding the impact of recreation on Dartmoor.

- The report addresses both the benefits and the costs of increased recreation activity on Dartmoor. With regards to benefits, a key measure is that of economic welfare. Welfare refers to the sense of well-being or utility experienced by an individual. Economic welfare is a figure capturing the monetary equivalent of this welfare enjoyed by visitors from their visits. Economic welfare can be directly estimated using the calibrated ORVAl tool. Indeed the model indicates that Dartmoor is currently the source of £25.6 million of welfare benefits to the residents of the 8 neighbouring LADs each year and that as a result of population increases that number will likely rise to £28.1 million by 2039; an increase in annual welfare of £2.5 million..
- Those welfare benefits are not evenly distributed across the neighbouring LADs. Rather the largest economic welfare values are realised in those LADs with significant populations in and around Dartmoor including Teignbridge, West Devon and Plymouth.
- The report also attempts to quantify the health benefits of the physical activity enabled by recreational access to the National Park. The footfall model provides prediction as to how far visitors to Dartmoor might be expected to walk in the National Park. Translating walking distances into energy expenditure provides an estimate of the level of fat burned by visitors, a quantity amounting to 100,000 kg of fat each year for the residents of the eight LADs neighbouring Dartmoor.
- Increased recreational activity on Dartmoor also generates the possibility of increased environmental and management costs. Transferring findings from a detailed study of the English Lake District, the report uses the footfall intensity estimates along with measures of path slope and altitude to predict rates of footpath erosion. Our analyses suggest that increasing recreational pressure on Dartmoor may result in 10,854 m^2 of bare ground being exposed along the path network and increased gullying along 42km of path.
- With regards to wildlife the research team carried out an extensive review of literature on the disturbance impacts of recreation. That review indicates that recreation impacts are complex and that it is difficult to make generalisations regarding how wildlife responds to recreation pressures. The report provides some detailed pen pictures of a selection of studies that are most relevant to the environment and wildlife of Dartmoor.
- To better understand the potential for recreational disturbance of wildlife on Dartmoor a selection of species of local, national and international importance,

were identified from two local publications, 'The State of Dartmoor's Key Wildlife' and the 'Devon Special Species List'. For each species a recreation impact questionnaire was conducted with a local expert. The questionnaire gathered information on the distribution of each species across the Dartmoor landscape and sought insights as to whether and how exposure to increased recreation activity might impaction on the species population.

- Our analysis identifies twelve species that stand as examples of species that might be vulnerable to disturbance from increased intensity of recreational activity. Examples of species of particular concern include Cuckoo, Nightjar, Ring Ouzel and Wood Warbler. Activity types which have negative effects differ between species, but walking, dog-walking and large events are key concerns across many of the investigated key species.
- Overlaying the distributions of those species with our estimates of increasing visitor pressure across the National Park allows us to highlight some species that might be a focus of concern and the locations in which they are made vulnerable by rising recreation pressures. Those locations include the areas around i) Burrator, ii) the Dart Valley and Venford Reservoir, iii) Haytor, iv) Warren House, Soussons and Fernworthy.
- At these sites, an increased conflict between recreation and wildlife can be expected, and mitigation measures could therefore be prioritised there. Mitigation measures derived from both expert opinion and past research are outlined in the report. Measures suggested to be beneficial to a broad range of species include (temporary) access restrictions, management of large events, enforcement of the dogs on lead policy and public education.
- Recommendations for future data collection and research are discussed. These include further study to establish footfall thresholds for wildlife disturbance, an assessment of footfall intensity in relation to erosion patterns, and a quantification of recreational activities across the National Park.

Population futures and Dartmoor National Park

Implications of development around the outskirts of Dartmoor for recreational use and management of access

September 2018

Report to Dartmoor National Park Authority

Brett Day
Amii Harwood
Charles Tyler
Sara Zonneveld

THIS REPORT IS A REDACTED VERSION OF A FULL REPORT PREPARED BY SWEEP FOR THE DARTMOOR NATIONAL PARK AUTHORITY. FIGURES AND TEXT CONTAINING INFORMATION ON HIGHLY SENSTIVE SPECIES HAVE BEEN REMOVED.

PLEASE DO NOT DISTRIBUTE THIS FILE WITHOUT PERMISSION FROM SWEEP OR DNPA – CONTAINS SOME SENSITIVE INFORMATION

sweep
Applying research to benefit our environment and economy

Acknowledgements:

The research in this report was funded by Dartmoor National Parks Authority and by the Natural Environment Research Council (NERC) through the SWEEP project.

We would like to thank all local species experts for sharing their knowledge on the local ecology and distribution of key species. The names of individuals who contributed by filling in key species questionnaires can be found in the full version of this report.

Executive Summary

- Dartmoor National Park is enjoyed by large numbers of visitors. Significant new housing developments and population growth in the districts around Dartmoor will inevitably result in increases in the number of visitors to the National Park.

- The statutory purposes for National Parks (Environment Act 1995) are to i) *"conserve and enhance the natural beauty, wildlife and cultural heritage"* and ii) *"promote opportunities for the understanding and enjoyment of the special qualities of national parks by the public"*.

- In connection with these statutory purposes, the aim of this report is to identify both how the expanding population of Dartmoor's hinterland will benefit from the National Park as a recreational resource and also how the pressure of the additional visits coming from those new residents will impact on the National Park's environment.

- The report is compiled by academics from the SWEEP project (www.sweep.ac.uk) at the University of Exeter, and draws on secondary data, modelling capacity and on expert inputs in order to present a comprehensive assessment of the recreational future of Dartmoor..

- The first major contribution of this report is to construct spatialized predictions of population change in the Dartmoor hinterland from 2014 to 2039. Those predictions draw on Office of National Statistics population projections augmented by details of proposed property developments described in the Local Plans of the eight Local Authority Districts (LADs) that surround the National Park.

- To understand how new residents of the region might use Dartmoor, the spatialised population projections have been coupled with the Outdoor Recreation Valuation (ORVal) tool. ORVal is a sophisticated recreation demand model developed by the LEEP institute at the University of Exeter. As part of this project a bespoke calibration of the ORVal tool was developed and used to predict current and future patterns of visits to the array of recreation sites across Dartmoor National Park.

- The model indicates that Dartmoor is currently the backdrop for over 7 million day trips per year from residents of the eight neighbouring LADs. Moreover, increased populations in those LADs will result in more than 870,000 additional annual visits to Dartmoor per year, a rise of some 12%.

- The report also describes the development of a second bespoke modelling tool that extends the ORVal estimates of visitation into estimates of intensity of footfall through the National Park. That model used evidence from various sources to approximate how far visitors might travel through the paths network during their visits. The resulting estimates of the spatial dispersion of visitors and the intensity of footfall across the National Park allows us to address a number of questions regarding the impact of recreation on Dartmoor.

- The report addresses both the benefits and the costs of increased recreation activity on Dartmoor. With regards to benefits, a key measure is that of economic welfare. Welfare refers to the sense of well-being or utility experienced by an individual. Economic welfare is a figure capturing the monetary equivalent of this welfare enjoyed by visitors from their visits. Economic welfare can be directly estimated using the calibrated ORVAl tool. Indeed the model indicates that Dartmoor is currently the source of £25.6 million of welfare benefits to the residents of the 8 neighbouring LADs each year and that as a result of population increases that number will likely rise to £28.1 million by 2039; an increase in annual welfare of £2.5 million..

- Those welfare benefits are not evenly distributed across the neighbouring LADs. Rather the largest economic welfare values are realised in those LADs with significant populations in and around Dartmoor including Teignbridge, West Devon and Plymouth.

- The report also attempts to quantify the health benefits of the physical activity enabled by recreational access to the National Park. The footfall model provides prediction as to how far visitors to Dartmoor might be expected to walk in the National Park. Translating walking distances into energy expenditure provides an estimate of the level of fat burned by visitors, a quantity amounting to 100,000 kg of fat each year for the residents of the eight LADs neighbouring Dartmoor.

- Increased recreational activity on Dartmoor also generates the possibility of increased environmental and management costs. Transferring findings from a detailed study of the English Lake District, the report uses the footfall intensity estimates along with measures of path slope and altitude to predict rates of footpath erosion. Our analyses suggest that increasing recreational pressure on Dartmoor may result in 10,854 m^2 of bare ground being exposed along the path network and increased gullying along 42km of path.

- With regards to wildlife the research team carried out an extensive review of literature on the disturbance impacts of recreation. That review indicates that recreation impacts are complex and that it is difficult to make generalisations regarding how wildlife responds to recreation pressures. The report provides some detailed pen pictures of a selection of studies that are most relevant to the environment and wildlife of Dartmoor.

- To better understand the potential for recreational disturbance of wildlife on Dartmoor a selection of species of local, national and international importance, were identified from two local publications, 'The State of Dartmoor's Key Wildlife' and the 'Devon Special Species List'. For each species a recreation impact questionnaire was conducted with a local expert. The questionnaire gathered information on the distribution of each species across the Dartmoor landscape and sought insights as to whether and how exposure to increased recreation activity might impaction on the species population.

- Our analysis identifies twelve species that stand as examples of species that might be vulnerable to disturbance from increased intensity of recreational activity. Examples of species of particular concern include Cuckoo, Nightjar, Ring Ouzel and Wood Warbler. Activity types which have negative effects differ between species, but walking, dog-walking and large events are key concerns across many of the investigated key species.

- Overlaying the distributions of those species with our estimates of increasing visitor pressure across the National Park allows us to highlight some species that might be a focus of concern and the locations in which they are made vulnerable by rising recreation pressures. Those locations include the areas around i) Burrator, ii) the Dart Valley and Venford Reservoir, iii) Haytor, iv) Warren House, Soussons and Fernworthy.

- At these sites, an increased conflict between recreation and wildlife can be expected, and mitigation measures could therefore be prioritised there. Mitigation measures derived from both expert opinion and past research are outlined in the report. Measures suggested to be beneficial to a broad range of species include (temporary) access restrictions, management of large events, enforcement of the dogs on lead policy and public education.

- Recommendations for future data collection and research are discussed. These include further study to establish footfall thresholds for wildlife disturbance, an assessment of footfall intensity in relation to erosion patterns, and a quantification of recreational activities across the National Park.

Table of Contents

Tables

Figures

1 INTRODUCTION

Dartmoor National Park is enjoyed by large numbers of visitors. Significant new housing developments and population growth in the districts around Dartmoor will inevitably result in increases in the number of visitors to the National Park. In order to ensure both high quality recreational experiences and successful environmental protection, there is a need to better understand how new housing developments will impact Dartmoor. In response to that challenge, the Dartmoor National Park Authority (DNPA) outlined the following key questions for which answers were needed:

- Where do visitors currently come from?
- How will housing levels change in the areas around the National Park?
- How may visitor numbers, visitor distribution and types of access change?
- What are the impacts from National Park access and how important are those impacts?
- What needs to be done in terms of mitigation or changes to access management to provide for the changes forecast?

This report, compiled by staff of the SWEEP partnership (www.sweep.ac.uk) at the University of Exeter, sets out to provide answers to those questions.

In achieving that goal the research team have drawn on numerous information sources bringing together secondary data, modelling capacity and drawing on expert inputs in order to present a comprehensive assessment of the impacts on Dartmoor of future population increases.

The report begins with an assessment of what those future population changes might look like. Drawing on population predictions provided by the Office of National Statistics, Section 1 uses information provided in the Local Plans of numerous Local Authority Districts (LADs) to provide a detailed spatial prediction of the distribution of population increases around Dartmoor.

Section 2 of the report begins the examination of future recreational use of the National Park. Using a bespoke calibration of the Outdoor Recreation Valuation (ORVal) Model for Dartmoor, we predict current and future patterns of visitation across the National Park. In particular, our spatial population growth forecasts allow us to identify the distribution and intensity of day visits that arise from the growing populations of the LADs in Dartmoor's hinterland. This forecast focuses on day visits only, overnight visitors are not included in the ORVal Model. Section 2 goes on to develop a model of route choice which builds on data from the Monitor of Engagement with Natural England survey to approximate how visitors use the National Park and, more specifically, how visitors disperse through the recreation paths network during their visits. Our model allows us to make predictions regarding the intensity of footfall along paths in the National Park on any particular day or hour during the year.

Section 3 of the report considers the benefits of the recreation experiences provided to visitors by Dartmoor National Park. The report focuses on two measures. The first is that of economic welfare, a monetary measure of the enjoyment that visitors realise from their visits. Economic welfare is the standard measure of benefit used in social cost-benefit analyses as prescribed by government guidance in the Treasury Greenbook. Those estimates are derived from the ORVal model and show that the National Park is responsible for millions of pounds worth of recreational benefit each year. More specifically, the predictions indicate that by 2039, Dartmoor will be offering services to the expanded population of neighbouring LADs that deliver some £2.5 million of additional recreation benefits every year.

The second measure of benefit addressed in Section 3 is that of physical activity. The footfall model developed in Section 2, allows us to predict how far visitors to Dartmoor might be expected to walk during their time in the National Park. Translating walking distances into energy expenditure allows us to estimate the level of fat burned by visitors. Those estimates suggest that residents of the 8 local LADs burn around 100,000 kg of fat each year as a result of their physical activities on Dartmoor.

Section 4 moves on to consider the costs of recreational activity on Dartmoor. Again we address two potential costs, the physical erosion of paths resulting from recreation activities and the disturbance that activity might call to Dartmoor's wildlife.

With regards to erosion, we transfer findings from a study done in the English Lake District that allows us to predict rates of erosion on paths to path slope and altitude and, most importantly, to the intensity of daily footfall. Our analyses suggest that increasing recreational pressure on Dartmoor may result in 10,854 m^2 of bare ground being exposed along the path network and increased gullying along 42km of path.

With regards to wildlife the research team carried out an extensive review of literature on the disturbance impacts of recreation. That review indicates that recreation impacts are complex and that it is difficult to make generalisations about how the environment and wildlife respond to recreation pressures. The report focuses in on a selection of studies that are most relevant to Dartmoor, particularly those that address wildlife impacts in upland, heathland, moorland and oak woodland. To support the literature review, a selection of key Dartmoor species of local, national and international importance, and representing a broad range of habitats and species groups, were selected and a recreation impact questionnaire conducted with local species experts. The purpose of that questionnaire was to gather insights into the distribution of each species across the Dartmoor landscape so as to understand where that population might likely be exposed to mounting recreational pressures as well as to seek expert opinion on the possible impacts of that exposure on species populations.

Our analysis identifies twelve species that stand as examples of species that might be vulnerable to disturbance from increased intensity of recreational activity. Superimposing the distributions of those species with our estimates of increased visitor pressure across the National Park allows us to highlight some species that might be a focus of concern. In addition our analysis allows us to identify locations of concern where vulnerable wildlife distributions are associated with places where particularly strong increases in footfall are expected between now and 2039.

This report presents evidence supporting the contention that population growth in the region around Dartmoor will result in significant increases in recreational use of the National Park. For those new residents of the region, Dartmoor offers a significant resource that will likely be the source of substantial economic welfare and also the backdrop that encourages significant physical activity. Of course, that activity will also have impacts on the National Park and drawing on best available evidence the report identifies the possible extent of increased erosion along Dartmoor's paths network and the species and locations most vulnerable to disturbance as a result of increasing recreational pressure.

2 POPULATION FUTURES

In order to assess the future impacts of recreation on Dartmoor National Park, we first need to draw together information on the magnitude and spatial distribution of population around the National Park and generate predictions of how that population might change going into the future. This first section describes the data sources and analyses that have been used in developing those population distribution predictions

2.1 THE DARTMOOR HINTERLAND

Due to their connectivity to Dartmoor National Park, our analysis focuses primarily on eight local government areas (i.e. Unitary Authorities and Districts) that define Dartmoor's hinterland (Figure 1). For simplicity we refer to these subsequently just as Local Authority Districts or LADs. Notice from Figure 1 that three of the LADs in Dartmoor's neighbourhood (West Devon, Teignbridge and South Hams) have some significant physical overlap with the National Park. Of the remaining neighbouring LADs, three (Exeter, Plymouth and Torbay) represent relatively urbanised areas while the Mid-Devon and East Devon are relatively rural and generally more remote from Dartmoor.

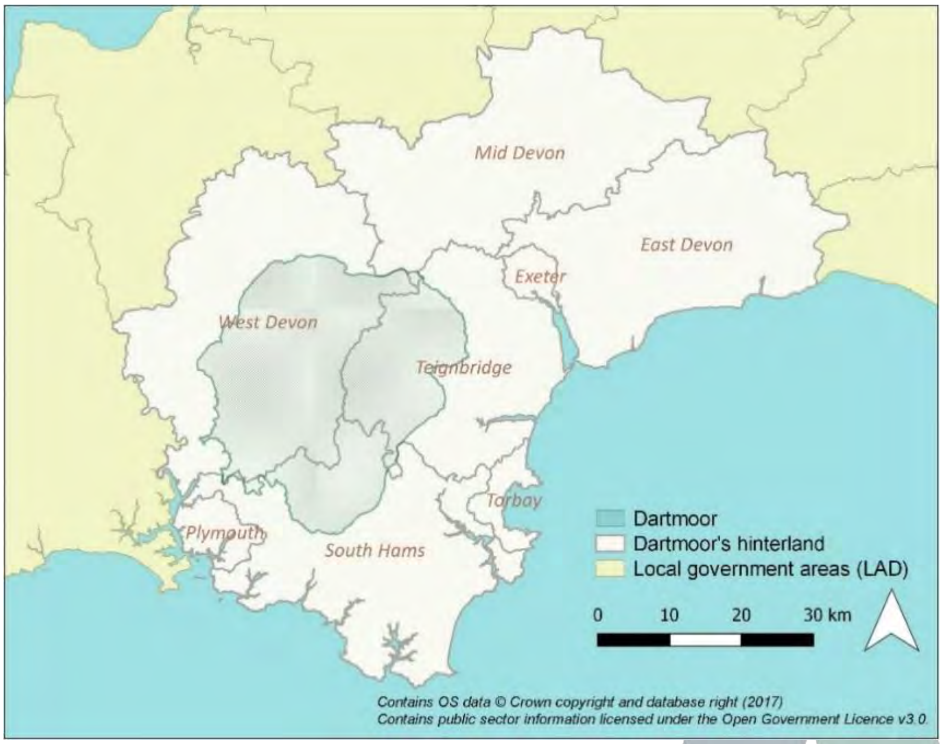


Figure 1. Dartmoor's hinterland as defined by eight LADs (as labelled).

Table 1 provides some details of the populations of the 8 LADs taken from the 2011 census. In this table we have focused on the adult population since our later analyses of recreation also focus on adult populations. Observe that the LADs' populations are different both in magnitude and the socioeconomic composition. Plymouth for example has by far the largest population (222,096 adults) but, along with Torbay, a relatively high proportion of residents in the lowest socioeconomic category (26.3%). South Hams, in contrast, has an adult population of only 72,757 of home only 17.2% are in the DE socioeconomic category.

Table 1: Adult population (> age 16) in 2011 and its distribution across socioeconomic segments for LADs in Dartmoor's hinterland (Source: 2011 census). Socioeconomic segments are displayed according to the National Readership Survey social grade classification system.

Region	Adult Populations				
	AB	C1	C2	DE	Total
East Devon	24.1%	30.0%	26.2%	19.8%	118,684
Exeter	21.9%	36.2%	20.4%	21.6%	108,914
Teignbridge	23.6%	29.9%	25.8%	20.6%	109,827
West Devon	24.6%	27.1%	28.1%	20.2%	49,467
Mid Devon	21.1%	26.5%	30.3%	22.2%	66,194
Torbay	15.8%	29.9%	25.9%	28.4%	112,798
Plymouth	15.9%	33.6%	24.2%	26.3%	222,096
South Hams	27.8%	29.4%	25.5%	17.2%	72,757
Total:	20.7%	31.2%	25.2%	22.9%	860,736

Each LAD is responsible for maintaining an up-to-date Local Plan which identifies how land in their area is to be used particularly with regards to what will be built and where. Under the Localism Act, in developing their Plans neighbouring LADs have a duty to cooperate, identifying and solving boundary issues, for a more integrated planning approach.

Following a scoping exercise of the provision for development in local plans, three such groupings around major settlements are important for Dartmoor (referred to herein as Plymouth and surrounds, Exeter and surrounds and Torquay and surrounds).

2.2 POPULATION PROJECTIONS

A key source of data for our subsequent analyses is provided by the Office of National Statistics (ONS) population projections. Those projections provide an indication of the future size and age structure of the population based on mid-year population estimates and a set of assumptions of future fertility, mortality and migration. The ONS releases those estimates at a variety of regional scales, with the finest spatial resolution being at the LAD level (ONS, 2014; DCLG, 2016). Accordingly we take ONS population projections at the LAD spatial scale selecting information at 5 year time slices starting from 2014 through to 2039 as the basis of our subsequent analyses.

Table 2 provides some headline details of those population projections for the LADs in Dartmoor's hinterland. Over the 25 years from 2014 to 2039, the population in the region is projected to increase by 13% from around 1 million people in mid-2014 to 1.1 million in mid-2039. Notice that in contrast to Table 1 the data refers to the entire population and not just the adult population. According to the ONS projections, the strategic grouping of Exeter and surrounds will see the greatest population increase of 77 000 people, Plymouth and surrounds will increase by 42 000 and Torquay and surrounds will increase by 15 000. Relative to its baseline population size, the local government area of East Devon will experience the greatest increase in population (17.9%).

Table 2. Population change in Dartmoor's hinterland, from mid-2014 to mid-2039 (Source: ONS 2014, SNPP Z1; rounded)

Strategic grouping	Unitary Authority or District (LAD)	Persons 2014	Persons 2039	Change	%Change
Plymouth and surrounds	Plymouth	262,000	287,000	25,400	9.7
	South Hams	84,000	92,000	7,600	9.1
	West Devon	54,000	63,000	8,600	15.9
Exeter and surrounds	Exeter	124,000	145,000	21,100	17.0
	Teignbridge	127,000	149,000	21,200	16.7
	East Devon	136,000	161,000	24,400	17.9
	Mid Devon	79,000	89,000	10,100	12.7
Torquay and surrounds	Torbay	133,000	148,000	15,500	11.7
Total		1,000,000	1,134,000		

The ONS projections are provided with a detailed estimate of the age and gender structure of the predicted population. Those age-gender compositions are illustrated in Figure 2. While the working age population will remain broadly similar, the predictions suggest increases to the number elderly will create an ageing population structure in the hinterland.

Our subsequent analysis of recreational activity on Dartmoor requires information not only on the size of population and its age and gender structure but also information on other socioeconomic details such as distribution across ethnic groups, distribution across socioeconomic segments and car ownership. In the absence of detailed predictions of those variables from the ONS we make the assumption they remain the same as those observed in the 2011 census data.

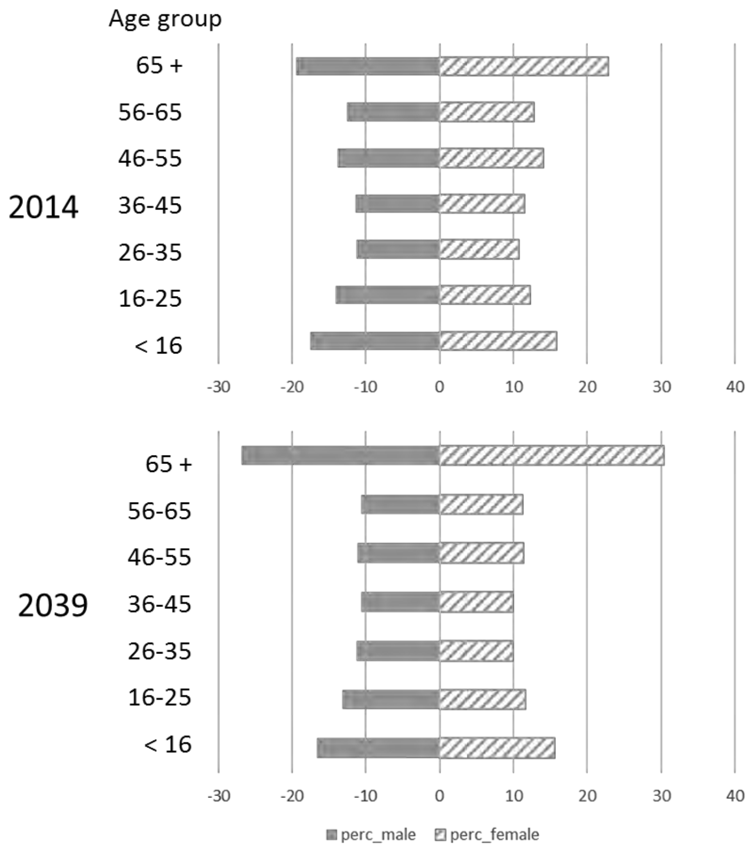


Figure 2. Changed population structure for Dartmoor's hinterland over a 25-year period (Source: ONS 2014, SNPP Z1)

2.3 LOCAL PLANS

The ONS predictions remain relatively coarse, detailing as they do, population information at the level of the LAD. In this project, our objective is to spatialize projections so as to provide population estimates at the level of the Lower Super Output Area (LSOA). LSOAs are reasonably small scale census areas with populations ranging from around 1,000 up to around 3,000. The key source of information we exploit in achieving that finer resolution distribution of population across LSOAs in a LAD is provided by the Local Plans.

We review the relevant plans here, highlighting information which provides insights as to where and when development is expected and therefore where population increases are likely to be concentrated.

2.3.1 Local plans for new homes – Plymouth and surrounds

Plymouth, South Hams and West Devon LADs have produced a Joint Local Plan (2014-2034) which is currently under review (JLP, 2017). This is an overarching strategic plan for the area of Plymouth and South West Devon that is outside of the Dartmoor National Park. The spatial strategy operates at three different levels: the Plan Area (Plymouth Housing Management Area – all three local authorities), the Plymouth Policy Area (Plymouth and urban fringe) and Thriving Towns and Villages Policy Area (rural South Hams and West Devon). Around 71% of growth is directed to the Plymouth Policy Area and 29% in the Thriving Towns and Villages Policy Area.

Housing provision is made for 26,700 new homes in the Plan Area (during the plan period 2014-2034). Within the Plymouth Policy Area there will be provision for 19,000 new homes (4550 affordable) and within the Thriving Towns and Villages Policy Area there will be 7,700 new homes (2050 affordable). The figure of 26,700 new houses includes an allowance of around 600 on Dartmoor, as well as allowance for second homes and vacant properties.

Analysis of Objectively Assessed Needs (OAN) for new housing used ONS population projections but these were criticised for their reliance on short-term trends, an inability to incorporate policy-led growth aspirations for Plymouth and capping to control the national projections (SHMNA, 2017; DCC, 2017). Local revised population growth is projected to 42,800 people (20,500 households) between 2014 and 2034 across the Plan Area (while official projections estimate 35,000 people, ONS 2014).

Although development will be through a phased release, this level of temporal resolution is not available through policy maps. For planning purposes, SHMNA (2017) assumes 881 households per year in Plymouth (189 of these labelled 'affordable').

2.3.2 Local plans for new homes – Exeter and surrounds

Information on developments within and surrounding Exeter are available from four local authority and district plans[1].

1. Exeter Core Strategy (2012-2026) outlines a development need for at least 12,000 dwellings. Of these, around 5,000 were being built or had been granted planning permission. A further 977 were identified within the urban area and 1048 from regeneration areas. Sustainable urban extensions (Strategic Allocation areas) were planned for Monkerton/Hill Barton (2,500), Newcourt (2,300) and Alphington (500).

2. East Devon Local Plan (2013-2031) describes housing development for 18 250 new homes, of these 10 550 new homes are near the border with Exeter.

3. Teignbridge Local Plan (2013-2033) outline housing provision of 12 429 dwellings over the plan period, with about 50% in the heart of Teignbridge and 15% in South West Exeter.

4. Mid Devon Core Strategy (2006-2026) outlines provision for new homes in Tiverton (6000 new homes), Cullompton (4000) and Crediton (2000).

The Exeter Core Strategy provides a graph estimating the trajectory of the developments over time. Mid Devon District Council provide development rates (average annual dwellings)[2] for two time periods for the area: 2006-2016 (390 dwellings per year) and 2017-2026 (290 per year). Development rates are alternatively provided by settlement (e.g. 145 per year in Tiverton, of which 43 are affordable). East Devon Local Plan provides a schedule for housing sites and numbers on an annual basis.

2.3.3 Local plans for new homes – Torquay and surrounds

The Strategic Housing Land Availability Assessment identifies a capacity of 11 200 new homes in the district over a twenty year period. The Torbay Local Plan (2012-

[1] Details of the forthcoming Greater Exeter Strategic Plan will not be available during the life of this project.

[2] These come from the Regional Spatial Strategy which was revoked following the General Election.

2030), however, states that constraints (e.g. infrastructure) set a more realistic target of 9 200 homes.

Over a third of houses in Torbay contain only one person. The Torbay Local Plan draws reference to DCLG household projections (7 550 new households; DCLG, 2016) in the Plan Period and population projections of 9 900 people. With a higher death rate than birth rate, the majority of population growth in Torbay is linked to inward migration. ONS projections have historically been adjusted downwards.

2.4 SPATIALISING POPULATION PROJECTIONS

As just reviewed, spatially explicit information on housing developments in Dartmoor's hinterland is available for the next 10-20 years from local government reports and plans. Many individual developments or Strategic Allocations can be mapped to LSOA(s) with confidence. Where not given, new population estimates can be inferred from the addition of new dwellings in a particular location making assumptions about average household size.

Temporally explicit information is somewhat inconsistent across the LADs. For example, assumptions need to be made about (average annual) development rates in Plymouth and surrounds. Likewise the Exeter Core Strategy and Mid Devon Core Strategy only plan development until 2026.

Our methodology for bringing together the ONS population projections and information from the Local Plans is undertaken in two stages:

- At Stage 1, we take the population predictions made by the ONS for a LAD and distribute this across all internal LSOAs. To mimic a natural growth rate, we spread that population increase out across LSOAs in proportion to each LSOA's share of the 2011 LAD population. Since LSOAs are generated to be reasonably consistent in terms of population size, this results in a reasonably even distribution of population increases across LADs.

- At Stage 2, while the baseline population in a LAD is evenly distributed across all internal LSOAs, population changes are redistributed proportionate to new homes (site allocations) in local plans. This runs until the end of the plan period. Beyond this, LAD-level projections are evenly distributed across all LSOAs.

Full details on population projections are available in Appendix 1 (national population projections) and Appendix 2 (population changes in Dartmoor's hinterland). Full details on methodology are provided in the full version of this report.

Our predictions of population change are made in 5 year time slices from 2014 to 2039. Figure 3 summarises the overall change in that period, mapping out the predicted population changes between 2014 and 2039 in the eight LADs of the Dartmoor hinterland. Notice that the increases in population show marked differences across space. The Cranbrook new town to the east of Exeter stands out as a location in which population is expected to grow rapidly. Similar, hotspots of predicted population growth can be seen around Okehampton to the north of Dartmoor, around Plymouth to the south west and Newton Abbot to the south east.

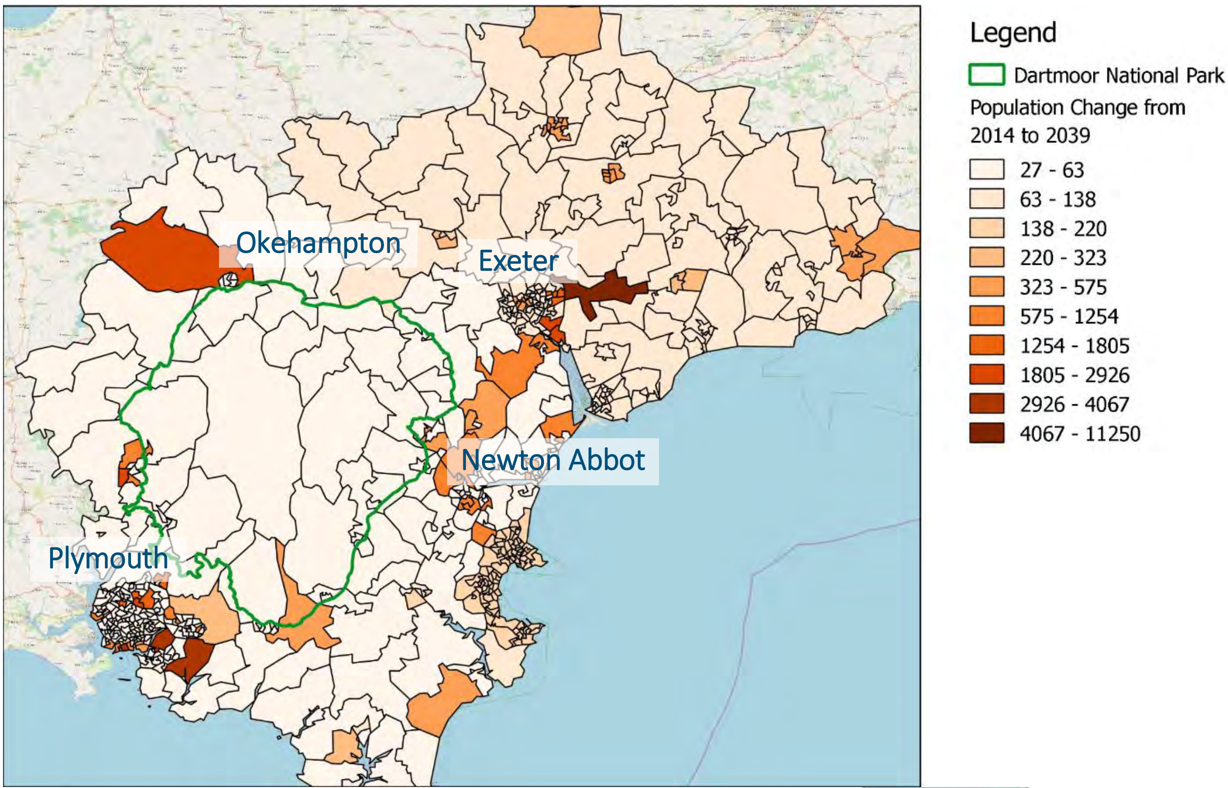


Figure 3: Projected population increases from 2014 to 2039 by LSOA

3 RECREATION FUTURES

Understanding the likely impacts of the future population changes described in Section 2 requires making forecasts about the future. In this project our approach to forecasting is to use models. In particular, we use models based on empirical data describing currently observed behaviour and use that to predict how future populations might be expected to behave. In this section, we describe how we develop those predictions, beginning with estimates of future trips to Dartmoor and progressing to a framework that allows us to estimate how footfall and intensity of use of the landscape might develop over the period to 2039. In particular, we look at how population growth in the 8 Local Authority Areas (LAAs) around Dartmoor is expected to contribute to that intensity of use.

3.1 THE ORVAL MODEL

The core modelling tool used in our analysis is the Outdoor Recreation Valuation (ORVal) model, developed by the LEEP Institute in the University of Exeter. The research in this project uses the soon to be released version 2.0 of the ORVal model (see Day and Smith, 2018).

The ORVal model is a statistical recreation demand model that can be used to predict the number of visits that are made by adult residents of England to different outdoor greenspaces. The model adjusts its predictions according to a number of factors, most particularly the socioeconomic characteristics of people, the day of the week, the month of the year, the attributes of a greenspace and the availability and qualities of alternative greenspaces. In this section, we briefly outline the key elements of this modelling tool but more detail can be found in Day and Smith (2018).

3.1.1 <u>Overview of the ORVal Model</u>

The ORVal model is estimated from data collected in the Monitor of Engagement with the Natural Environment (MENE) survey from 2009 to 2016. The MENE survey provides information on the recreational behaviour of a very large, representative sample of adults (over 16 years of age) resident in England. Over the course of a week, each respondent records when they visited greenspaces and for one randomly-selected visit the exact location of that visit and the mode of transport used in travelling to and from that recreation site.

Estimation of the ORVal model requires locating the particular greenspace visited by each respondent in the sample. Indeed, since the model assumes that visitors are making a choice between different greenspaces, a fundamental building block of the ORVal model is a map of greenspace locations across England and Wales which we describe in the next section.

The fundamental assumption of the statistical model is that the choices observed in the MENE data are welfare-maximising. By 'welfare' we are referring to the sense of well-being or utility that an individual feels from their experiences. So when an individual is observed to have taken a trip to enjoy a greenspace, we assume that the welfare of taking a trip at that time exceeds the welfare of doing something entirely different (say watching the TV or going shopping). Likewise when an individual is observed to have chosen a visit to one particular recreational site, we assume that the welfare derived from that visit exceeds the welfare that would be enjoyed from visiting an alternative site.

Without going into detail, the ORVal model is an example of a discrete choice model which attempts to capture the key decisions in recreational activity; whether to take a trip, which recreation site to visit and whether to travel to that site on foot or by car. The statistical framework within which this model is estimated directly addresses the question of substitution; that is to say, it tells us how visitors choose one particular outdoor recreation trip over other possibilities and even which other choices they might have made if their preferred option were not available to them.

In the model, a large number of variables are used to capture important arguments in the welfare function that determines choice. For example, the welfare that a person gets from taking a trip is modelled as depending on a person's socioeconomic characteristics, the location in which they live, the weather, the day of the week and the month of the year. In a similar vein, the welfare derived from visiting a particular greenspace is modelled as a trade-off between the benefits of enjoying time at that site and the costs incurred in getting there. In the model, those on-site benefits depend on the size, land covers, environmental qualities, water margins, designations and points of interest that characterise a particular greenspace. Likewise, the costs of getting to the site depend on whether they choose to walk or drive to that greenspace and the time and money costs of making that journey.

Ultimately, the statistical analysis presents us with an estimate of the function that determines the welfare an individual gets from making different recreational choices and determines the choices they might make given the options open to them. Of course, since this is a statistical analysis the model is probabilistic; in other words, it is only capable of making probabilistic predictions; how likely is it that a person with particular characteristics living in a particular location will choose to take a visit to greenspace on some particular day? How likely it is they will choose to visit some particular greenspace? How likely is it that they will choose to walk rather than drive to that greenspace?

In this project we use the probabilities predicted by the ORVal model to predict visits to Dartmoor. The model allows us to disaggregate those predictions in a number of ways. In particular, we can disaggregate them by home location in order to examine the contribution to visits made by residents of the eight LAAs in the Dartmoor hinterland. We can make predictions as to how many of those trips are made by car as opposed to on foot. Moreover, we can disaggregate trips by the locations on Dartmoor at which visitors begin their recreational activity in order to understand how recreational activity is spread across the National Park.

3.1.2 The ORVal Greenspace Map

The ORVal greenspace map is a detailed spatial dataset compiled through the combination and manipulation of a large number of primary data sources that describes the location and characteristics of accessible greenspace across England and Wales. Details of the construction of the ORVal greenspace map is provided in Day (2016). In brief, the recreation features identified on the ORVal greenspace map come in three basic forms;

- parks which consist of areas of accessible greenspace within well-defined boundaries over which visitors usually have freedom to wander at will,
- paths which consist of accessible, walkable routes that pass through the landscape, often traversing a variety of different greenspaces and tending to restrict visitors to defined routes of passage.
- beaches.

The paths stretches identified in the ORVal greenspace map are those that plotted on the Open Street Map project. Paths tagged as not being publically accessible or not passing through greenspace were removed. Using a simple recursive function path stretches were connected into networks. Finally, access points to each path network were identified by finding dangling ends of paths in a network within 50m of roads.

In some cases a paths network was served by a number of access points in close proximity. Since those access points present visitors with a very similar recreational opportunity we replaced groups of two or more access points that were not further than 250m from each other with a single approximating access point at the centroid of the group. For that reason, some access points in the ORVal paths data layer do not lie exactly on the intersection of a path and road.

In what follows we consider parks and path access points (and beaches) as being the foci of outdoor recreational trips and refer to these jointly as recreational sites. Each recreation site is described by various aspects of its physical characteristics;

- Landcover: For parks the quantity of each different landcover is recorded as the hectares of that landcover in the park boundary. For paths landcovers are defined by the quantity of different landcovers found in a 25m buffer either side of that path. In addition, we assume that there is a declining likelihood that a visitor will encounter some particular stretch of a paths network the farther that stretch is from the path access point. We calculate the land cover characteristics associated with accessing a paths network from some particular access point as a weighted sum over the length of a path with the weights declining linearly from a value of 1 for locations at the access point to 0 at a distance of 10km from that access point. Landcovers recorded in the ORVal greenspace map include broadleaf woodland, coniferous woodland, felled or young woodland, wood pasture, agriculture, natural grass, moors and heath, mountain, coastal, saltmarsh, marsh and fen, managed grass, sports pitches, gardens, allotments and cemeteries.
- Water margins: The presence of water at recreation sites is captured through the length of water margins. Four different forms of water are recognised; rivers, lakes, estuaries and sea. The data also records of the WFD ecological status of rivers and the bathing water quality at beaches.
- Designations: The ORVal greenspace map records the extent of recreation site in a National Park, AONB, Heritage Coast, National Trail, Historic Park, Millennium or Doorstep Green, or with some form of nature conservation designation.
- Facilities and Points of Interest: The dataset also records the presence of various facilities and points of interest including the existence of a car park, a children's playground, an archaeological feature, historic building, scenic feature (e.g. water fall) or a viewpoint. Figure 4 provides an excerpt from the ORVal greenspace map showing recreation sites within the boundaries of Dartmoor National Park. The map identifies 118 recreation sites classified as

parks and a further 549 path network access points within the National Park boundaries.

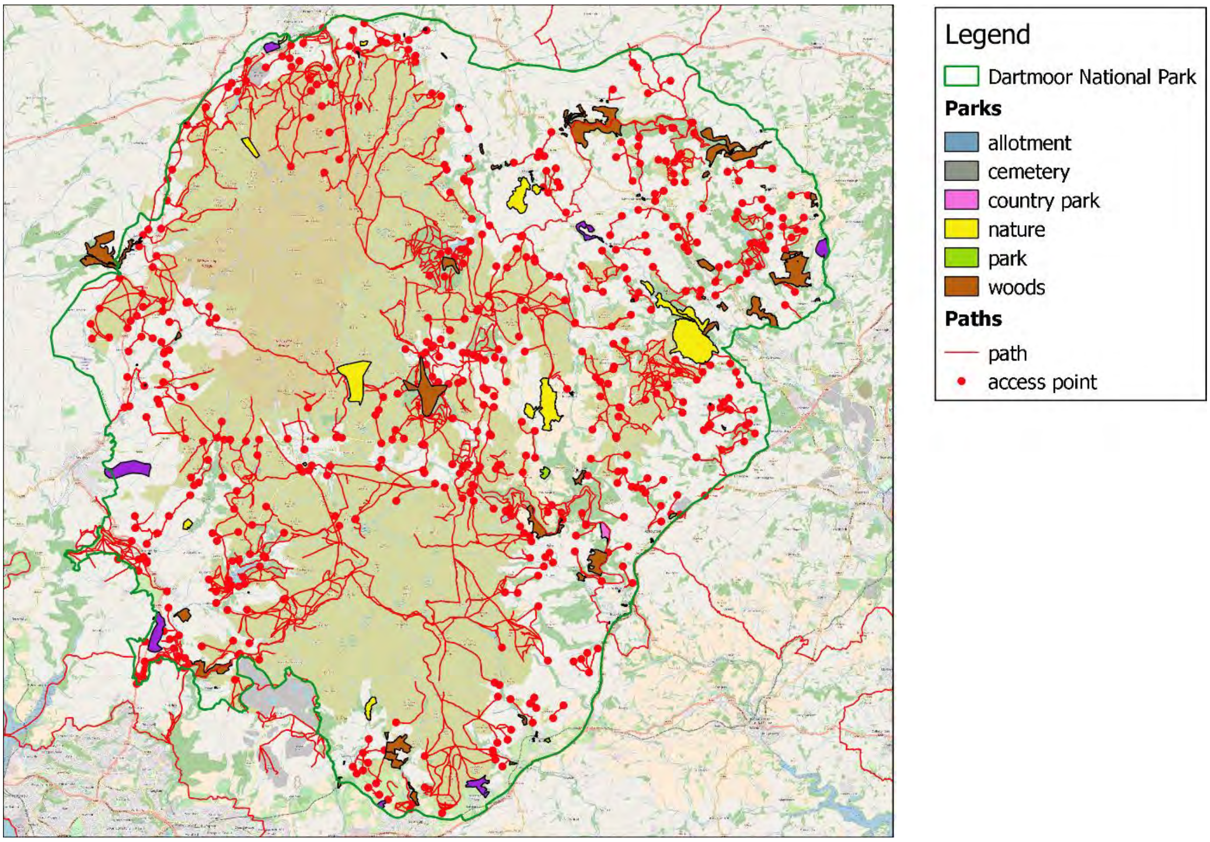


Figure 4: The network of recreation areas in Dartmoor National Park

3.1.3 Predictions using the ORVal model

The ORVal recreation demand model can be used to estimate the number of visits to different greenspaces. In particular, the model allows us to predict how likely it is that an individual will take a trip to a particular greenspace on a particular day. That likelihood differs according to the socioeconomic characteristics of the person, the attributes and proximity of the greenspace and the attributes and proximity of alternative recreational greenspaces.

To generate estimates of the annual number of visits to a particular greenspace we draw on the data outlined in section 2 regarding the size and characteristics of populations in each LSOA across England. Visitation predictions for each particular access point on Dartmoor are reached through the following set of calculations:

- Since participation differs across day of the year and across socioeconomic segments, for each LSOA we first find the number of adults in each socioeconomic segment (i.e. segments A&B, C1, C2 and D&E).
- For a particular day of the year we find average weather conditions in that LSOA and then use the ORVal model to calculate the probability of an adult in a particular socioeconomic segment taking a trip to the focus access point on that particular day at that particular time of year. We then multiply up by the number of adults in that segment in that LSOA.
- Repeating those calculations for individuals in each other socioeconomic group provides an estimate of the expected number of visits from that LSOA to that access point on that day.
- We reach an annual visitation figure from an LSOA by summing expected visitation numbers calculated for each different day of the year.
- Finally, we repeat those calculations for each of the 32,844 LSOAs in England and sum the results to arrive at a final prediction of the annual number of visits to a particular access point.

In addition to predictions of annual visitation, the ORVal model can also provide other interesting predictions regarding trips to a site;

- Visits by mode of transport: predictions of how many of the visits to a site are made by car or on foot.
- New visits: predictions of the number of 'new' visits generated by the site. Here the model is examining the substitution possibilities open to people visiting a particular site. Clearly, some of those visits will be by people who would go to an alternative greenspace if that particular site were not available. On the other hand, some of the trips will be made by people who would otherwise simply not have made a trip to an outdoor greenspace. The new visits reported by the tool are estimates of how many of the visits to a particular site are greenspace trips that would not have occurred without that site.

The ORVal model can also be used to estimate welfare values for greenspaces. By 'welfare value' we mean a figure describing the monetary equivalent of the welfare enjoyed by individuals as a result of having access to a greenspace. In economics this welfare value is often alternatively called an 'economic value' or a 'willingness to pay'. Welfare values are useful for decision-makers in applying cost-benefit analysis to appraise projects or policies that impact on greenspace.

Our calculation of welfare values is enabled by the fact that the recreation demand model provides an estimate of the recreation welfare function. That function identifies how much welfare an individual enjoys as a result of beneficial attributes of a greenspace (e.g. the extent of woodland, the presence of a children's playground). Likewise, it identifies how much welfare is lost from each extra pound of cost incurred in travelling to a greenspace. The latter amount is crucial in calculating welfare values. It tells us the amount of welfare a person considers is equivalent to having one extra pound. In other words, it provides an exchange rate that we can use to convert estimates of changes in welfare into equivalent amounts of money.

Welfare values for an existing recreation site are estimated by calculating how much each individual's welfare would fall if they were no longer able to access that site and then converting that welfare quantity into an equivalent monetary amount. Those welfare values can then be aggregated over the adult population of England for an entire year using the same sequence of steps as used to aggregate estimates of visitation. We return to consider welfare values in section 4.1.

Applying the ORVal model to the 2014 population estimates provides us with our initial estimates of recreation activity on Dartmoor and its distribution across the National Park. The headline figure from that analysis suggests that Dartmoor currently receives around 7,758,500 visits from adult residents of England over the course of a year.

One short-coming of ORVal is that it is unable to account for each of the multifarious features of recreation sites that determine how attractive they are to visitors. Put simply, ORVal uses observed behaviour to provide an estimate of how many visitors we might expect at a recreation site given its broad characteristics; its extent, its landcovers, whether it provides access to some special feature (e.g. an archaeological site or a scenic feature) whether it has a car park etc. While it accounts for those broad characteristics ORVal is unable to deal with the idiosyncratic features of each and every site; for example, it does not distinguish between the recreational experience of visiting Stonehenge or Hay Tor compared to some other less iconic archaeological remain or rock outcrop.

To address this issue, the baseline ORVal predictions were adjusted through a process of calibration to ensure they better captured the varying attractiveness of sites across Dartmoor. As a first step, we gathered the various recreation sites shown in Figure 4 into 45 groups that provided access to similar geographic areas of the

National Park. The areas identified by those groupings are shown as the green cells outlined in green on Figure 5. The left hand panel of that Figure shows the baseline ORVal estimates of visits to each area based on the 2014 population estimates.

A panel of experts from Dartmoor National Park Authority were convened to review those estimates alongside information provided by various visitor and car counters across the National Park. Drawing on that expert knowledge and observed data the model was recalibrated, introducing new parameters to the model whose values reflected the idiosyncratic features of those sites that made them more or less attractive to visitors than was suggested by the baseline model.

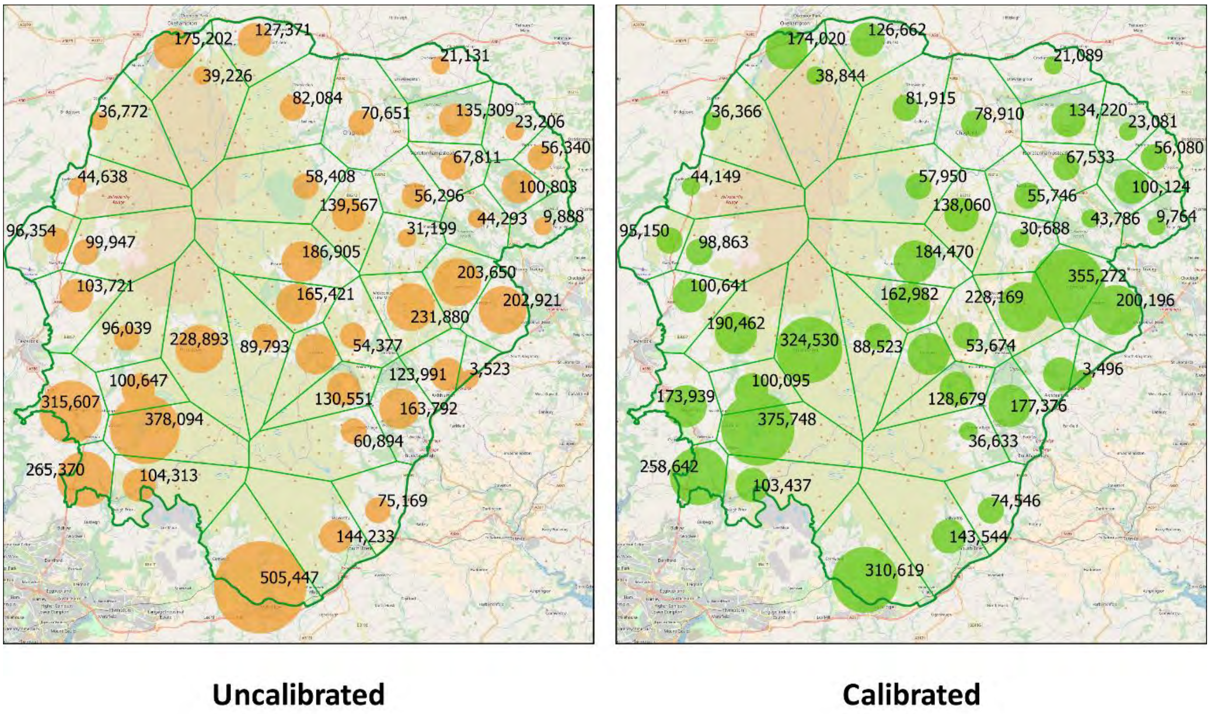


Figure 5: ORVal uncalibrated and calibrated predictions of visits to groups of access points across Dartmoor using 2014 population

To attribute values to those calibration parameters, an iterative algorithm was written that searched for a set of parameter values that best matched the expert input while maintaining the level of overall visitation to Dartmoor suggested by the baseline model (the assumption here is that the ORVal model does a good job at estimating overall visits but improvements can be made in the predictions of the distribution of those visits across the National Park). In order to make that algorithm manageable the focus of attention was reduced to visitors form the south west of England, a restriction that sped up iterations of the algorithm 10 fold. Accordingly, while the calibrated model made predictions of overall visits that are identical to that of the uncalibrated model for the population of the south west, it ended up suggesting an additional 6,500 visits from England as a whole (an error of less than one tenth of one percent). The predicted patterns of visitation from the calibrated model are shown in the right hand panel of Figure 5. Notice that the calibration parameters have concentrated more visits to the 'honey pots' such as those at Princetown and Haytor.

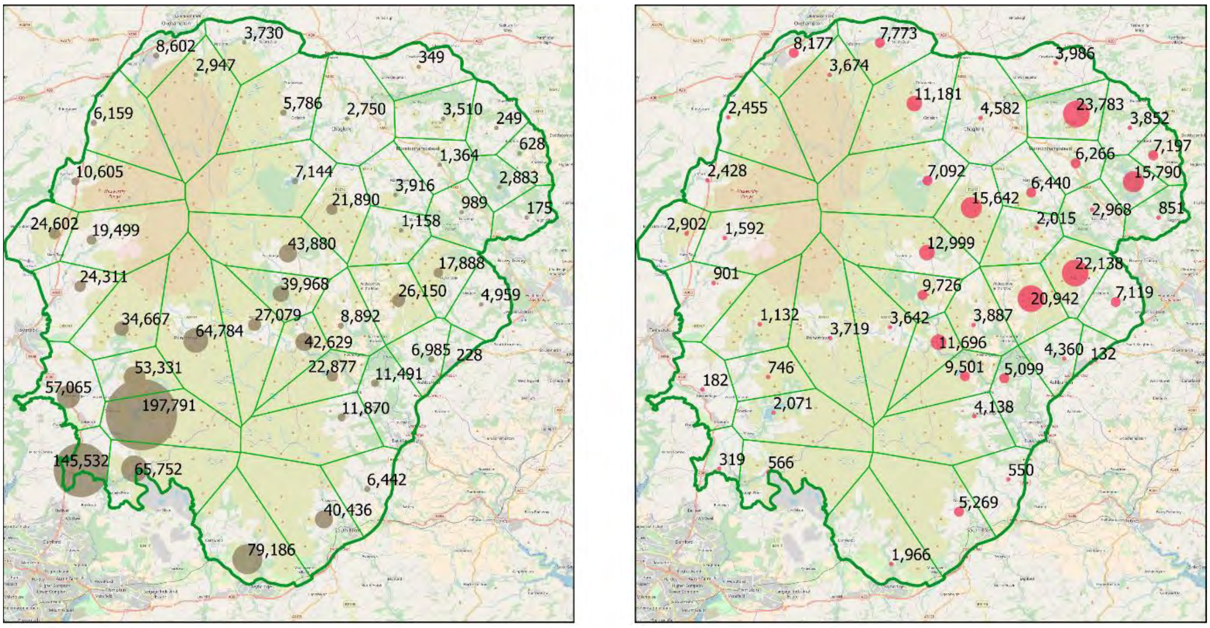
Applying the calibrated model to the 2014 population estimates allows us to provide estimates of visits to Dartmoor. Table 3 presents those estimates calculated for England as a whole and then the contributions to that total visitation from each of the 8 LADs in the neighbourhood of the National Park.

Table 3: Visit and welfare predictions for Dartmoor recreation day visits from England and neighbouring Local Authority Districts for 2014 population estimates

Region	Visits	% On foot	% New Visits
England	7,765,104	0.25	0.30
East Devon	210,908	0.00	0.37
Exeter	429,031	0.00	0.35
Teignbridge	1,899,369	0.39	0.27
West Devon	1,500,946	0.53	0.25
Mid Devon	230,784	0.02	0.34
Torbay	473,268	0.00	0.35
Plymouth	1,374,116	0.01	0.34
South Hams	992,481	0.42	0.27

From Table 3 we see that of the total 7.8 million estimated visits to the National Park, 25% are predicted to be made by travelling to the recreation site on foot. Of course, visits made on foot are only likely to be made by those living in or very near to the National Park. That fact is reflected in the information for the separate LADs, where we see significant numbers of trips on foot emanating only from those areas that overlap the National Park; Teignbridge, West Devon and South Hams (see Figure 1). The ORVal model also estimates that 30% of the visits to Dartmoor are 'new' visits; that is, without being able to access Dartmoor, those visits to outdoor greenspace would not have happened.

Table 3 also makes clear that the majority of the predicted visits, some 92%, come from the 8 neighbouring LADs. Recall the focus of the analysis is recreation day visits so the concentration of visits from relatively proximate locations is not surprising. Of course, the locations in the National Park that are closest to any visitor will depend on where they live. Indeed the ORVal model allows us to derive predictions as to where residents of each individual LAD are likely to recreate on Dartmoor. Figure 6 illustrates this difference in preferred destination for the two urban LADs of Plymouth and Exeter. Observe how visitors from Plymouth focus trips on areas in the south west of the National Park that are nearest to that city, while visitors from Exeter tend to visit locations in the east of the National Park that are relatively closer to Exeter.



Plymouth **Exeter**

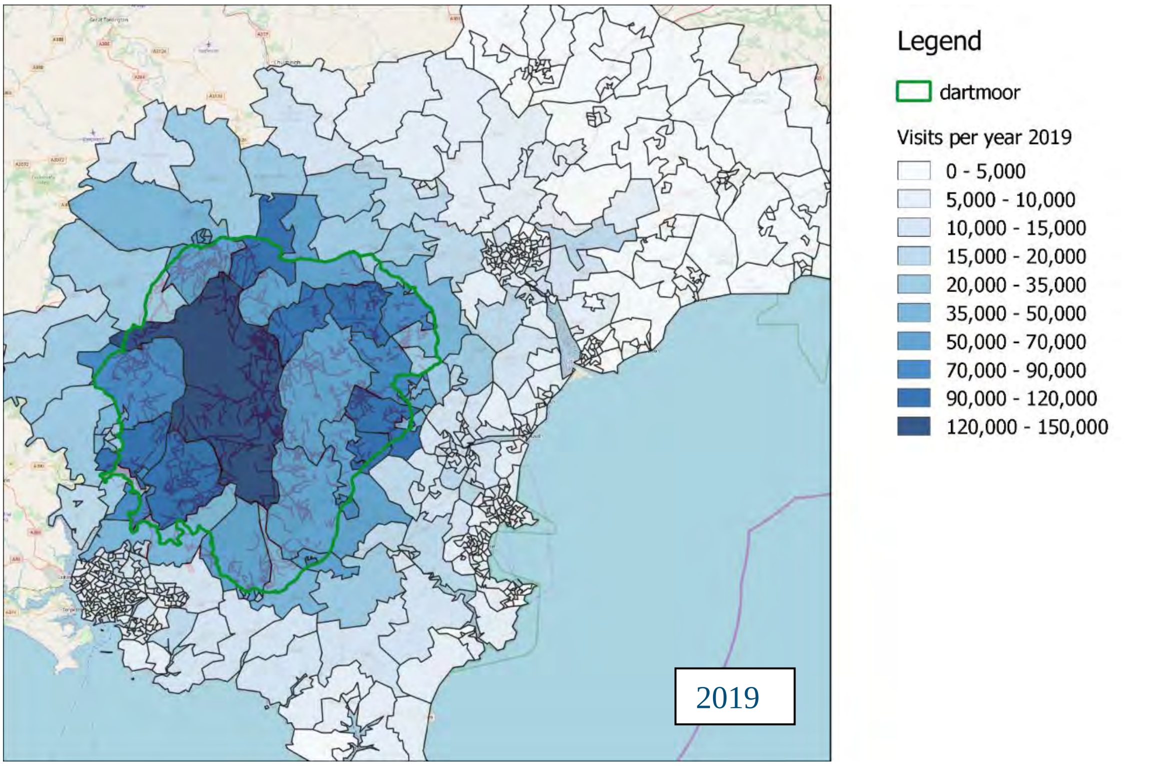
Figure 6: Distribution of estimated visits in 2014 from Plymouth and Exeter LADs

3.2 PREDICTING FUTURE LEVELS OF RECREATION ON DARTMOOR

Most importantly for our purposes, the calibrated ORVal model allows us to make predictions regarding visits from the expanding populations of the 8 neighbouring LADs. A summary of those predictions of future visitation is provided in Table 4. Figure 7 provides yet more detail illustrating the annual quantities of visitors to Dartmoor from each LSOA in the local region both in 2019 and in 2039.

Table 4: Growth in predicted visits to Dartmoor National Park 2014-39

LAD	2014	2019	2024	2029	2034	2039	Change 2014-39
East Devon	210,908	224,005	240,233	256,727	271,443	278,587	32.1%
Exeter	429,031	446,877	459,191	477,393	492,139	506,672	18.1%
Teignbridge	1,899,369	1,937,994	1,983,966	2,033,513	2,078,499	2,136,734	12.5%
West Devon	1,500,946	1,560,296	1,577,714	1,599,585	1,617,671	1,650,840	10.0%
Mid Devon	230,784	234,852	239,714	244,713	251,192	257,132	11.4%
Torbay	473,268	481,883	494,208	508,203	521,194	533,101	12.6%
Plymouth	1,374,116	1,413,406	1,438,915	1,476,701	1,506,000	1,532,663	11.5%
South Hams	992,481	1,015,249	1,029,116	1,050,436	1,067,131	1,087,488	9.6%
Total:	7,110,903	7,314,562	7,463,057	7,647,271	7,805,269	7,983,217	12.3%



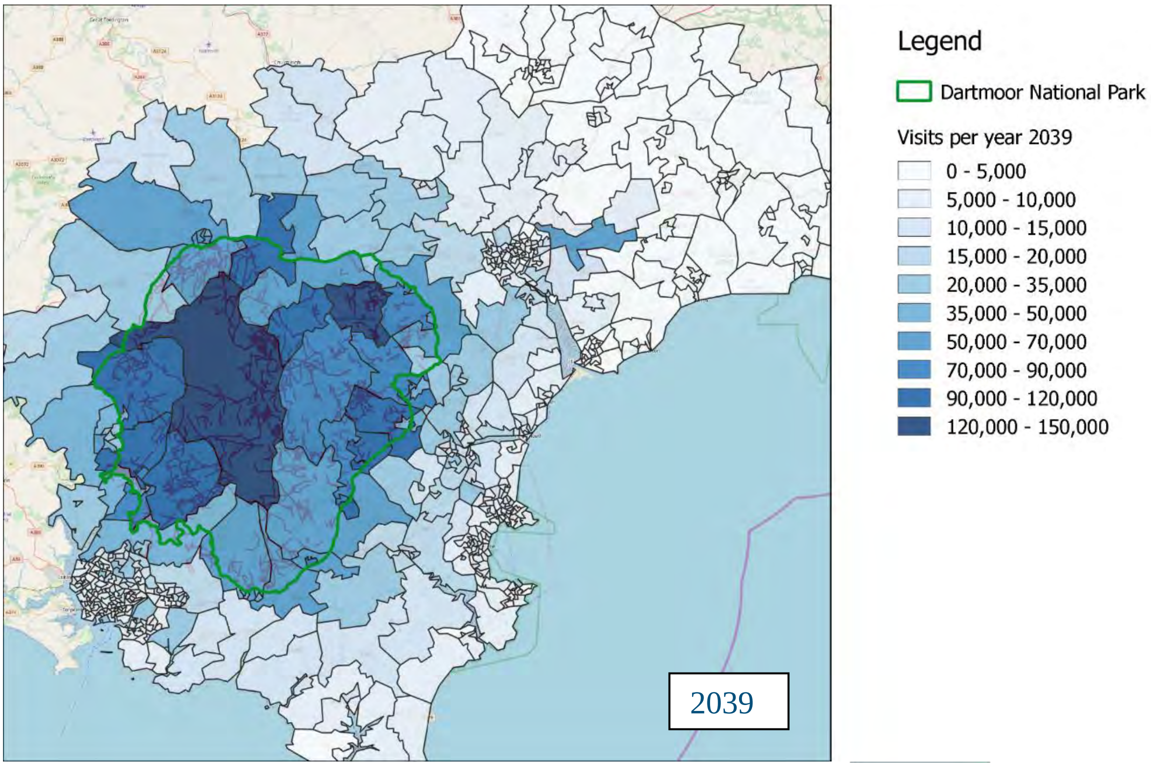


Figure 7: Numbers of annual visits to Dartmoor originating from each LSOA in 2019 (top panel) and 2039 (bottom panel). LSOAs from Dartmoor's eight neighbouring LADs are displayed.

Notice that as we go through time the LADs responsible for the largest quantity of visits are still those with a significant population residing within or on the border of the National Park. Obviously, those populations are far more likely to use the recreational opportunities on their doorstep than those who have to travel a significant distance to get to Dartmoor. Notice also from Table 4 that the largest percentage increase in visitation comes from the relatively remote East Devon LAD. An indication of why this is so can be seen from the dark blue shaded LSOA that appears in East Devon just to the right of Exeter in the 2039 predictions displayed in Figure 7. That LSOA contains the new town of Cranbrook whose population is expected to rise to over 10,000 residents by 2039. The growth of visitors from Cranbrook is even more evident in Figure 8 which depicts only the predicted increase in visitation from each LSOA in 2039 compared to 2019. In addition to Cranbrook, Figure 8 highlights a number of other locations where population increases (see Figure 3) are expected to result in large visitation increases including those around Okehampton to the north of Dartmoor, Plymouth to the south west, Newton Abbot to the south east and Exeter to the east.

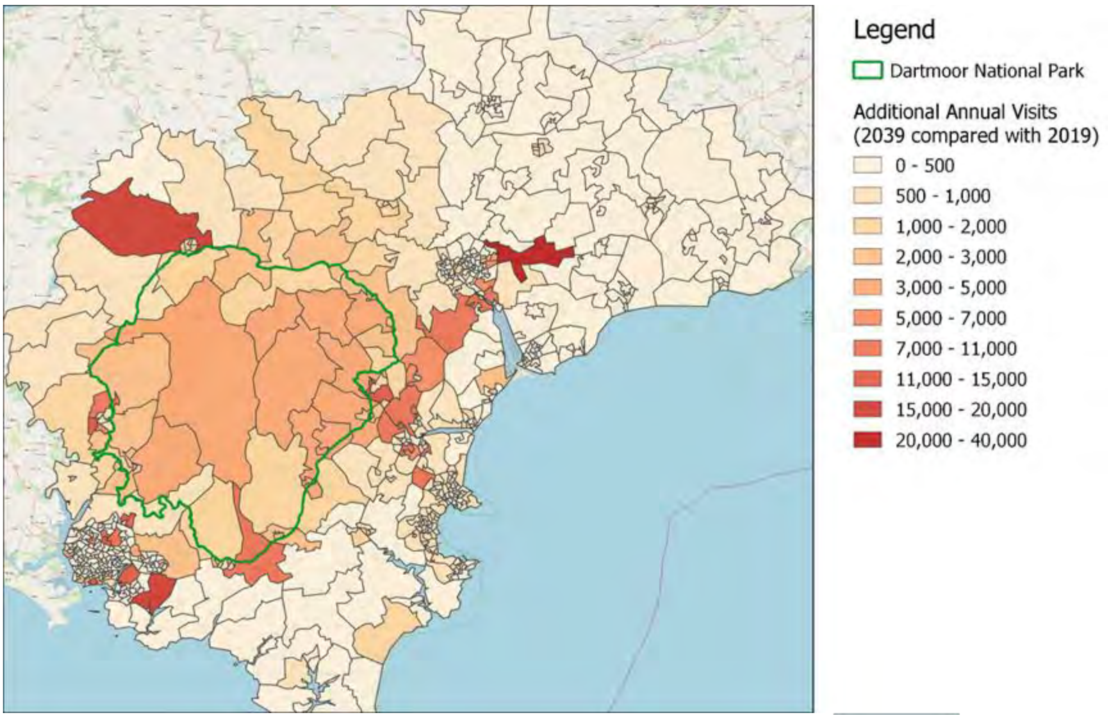


Figure 8: Increase in visitors from 2019 to 2039 from LSOAs in neighbouring LADs.

3.3 PREDICTING RECREATIONAL ACTIVITY ACROSS DARTMOOR

A central objective of this project is to develop an understanding of the possible impacts of increased visits to Dartmoor. To do that we not only need to know the levels of future visitation to access points on Dartmoor but also something about those visitors activities and how that translates into intensity of use across the Dartmoor landscape.

3.3.1 Characterising Visitor Activities

While the ORVal model provides us with an insight into the distribution of visits across Dartmoor, it does not tell us anything about their subsequent activities. Unfortunately, reliable statistical information on visitor activities on Dartmoor is scarce. Table 5 summarises data from the MENE survey of recreation day visits taken by English residents to the upland national parks of England. The MENE survey asks respondents about their activities and in Table 5 these are organised into two basic types; those that focus on roaming across the landscape and those that are focused on undertaking some particular leisure activity usually in a particular location (e.g. fishing, eating out, visiting an attraction etc.).[3] A further 'other' category captures those outdoor pursuits that are not specified in the MENE survey where 'climbing' is given as an example of such an activity. For our purposes, we assume that this 'other' category can be taken as being more similar to leisure activity recreation than roaming recreation.

Observe from Table 5 that the pattern of recreation activity is reasonably similar across the upland National Parks with the exception of Northumberland National Park where far fewer visitors partake in walking but relatively more engage in off-road biking and wildlife watching. The distribution of activities in Dartmoor is reasonably typical of the remaining upland National Parks. We find that 78% of visitors come to Dartmoor to walk or run, with some 43% of those 78% being accompanied by a dog. Other roaming activities such as off-road biking and horse-riding occur, but are relatively infrequent. Activity-focused recreation, therefore, accounts for 19% of visits, with the category 'food & games', (which includes eating out, picnicking, playing with children and playing informal games) representing the largest share of those activities.

[3] Note that as with the ORVal model we exclude visits where the respondent indicated their activity was road-biking or enjoying the countryside from their car.

Table 5: Activities during visits to upland National Parks in England (from MENE 2009-2016)

Activity	Dartmoor	Exmoor	Lake District	North York Moors	Northum-berland	Peak District	South Downs	Yorkshire Dales	All Upland Parks
Roaming Recreation									
Walking & running	78.0%	73.2%	79.4%	81.2%	21.4%	72.6%	83.0%	78.7%	76.5%
no dog	*44.4%*	*44.7%*	*62.0%*	*48.5%*	*16.7%*	*54.4%*	*47.4%*	*65.3%*	*51.9%*
with dog	*33.6%*	*28.5%*	*19.2%*	*32.6%*	*47.6%*	*15.8%*	*35.5%*	*13.7%*	*25.4%*
Horse riding	1.4%	0.8%	0.2%	1.2%	7.1%	1.4%	0.1%		0.9%
Off-road biking	1.1%	3.3%	3.3%	4.1%	17.9%	3.5%			2.7%
Boating & kayaking	0.7%	1.6%	2.2%	0.2%	2.4%	0.5%			0.7%
Leisure Activity Recreation									
Food & play	5.1%	4.1%	3.5%	2.9%	26.2%	9.5%	0.9%		4.7%
Visit an attraction	4.0%	5.7%	3.3%	2.5%	1.2%	7.1%	6.0%	8.2%	5.1%
Fishing	2.2%	0.8%	0.8%	1.4%	4.8%				0.7%
Shooting	1.8%	5.7%	2.9%	2.9%	2.4%	3.4%	4.1%	2.7%	3.3%
Watch wildlife	0.4%	1.6%	0.2%	1.0%	15.5%	1.8%	0.6%		1.3%
Other	5.4%	3.3%	4.1%	2.7%	1.2%	2.5%	5.2%	10.4%	4.2%
Observations in MENE	277	123	510	487	84	733	782	183	3,179

To progress, we make the assumption that the patterns of activity in the future will remain similar to those suggested by the MENE data. In other words, we assume that 81% of visits to those access points will be for the purposes of roaming recreation and 19% of visits will be for leisure activity recreation. Likewise, we make the assumption that that same mix of activities is observed at each different site (access point) in the National Park. In reality, of course, the relative levels of the two forms of recreation activity will differ across activity points. We know for example, that leisure activity recreation will be concentrated in locations endowed with the relevant leisure facilities and attractions (e.g. cafes, picnic sites, archaeological points of interest, etc.). Within the constraints of this project, however, we have not been able to achieve that level of detail in our consideration of distribution of activities across the National Park.

3.3.2 Distribution of Walking Distances

In order to translate predictions of visits to National Park access points into measures of intensity of use of the Dartmoor landscape the next step is to develop predictions of where and how far visitors travel through that landscape. Our division of recreation activities into roaming and leisure activity recreation is designed to enable that translation. In particular, we consider the objective of roaming recreation to be one in which a visitor transports themselves to a National Park access point and then derives benefit primarily from moving, perhaps large distances, through the landscape. For simplicity, we assume that visitors making such trips take round trips, returning to their original access point. In contrast, we assume that visitors engaging in leisure activity recreation transport themselves to an access point that is in easy reach of the location in which they wish to undertake their leisure activity then walk to and from that location.

As shown in Figure 4, we imagine the Dartmoor recreational landscape as being a network of paths and National Parks accessed from particular locations that we describe as access points. To understand intensity of use we need to be able to predict how far different visitors will pass through that network while pursuing their recreation activities. Our ultimate goal is to predict intensity of use of each location along the recreation network. The two forms of recreation imply very different depth of penetration of the recreation network by visitors setting out from some particular access point.

With respect to roaming recreation, we require some measure of the distribution of distances walked by visitors to National Parks participating in in such activity.

Unfortunately, no direct evidence of that distribution was available from data available for Dartmoor. An extensive search of the literature, however, revealed a recent survey of visitors to the Lake District National Park carried out by Nick Davies in 2016 as part of his PhD research. Amongst many other questions, that survey asked a sample of 518 visitors to record the distance of their walk in the National Park. The survey was carried out at a large number of different access points, with data being collected in every month of the year and on weekdays and weekends.

The data reported categorise length of trips into ones under 2 miles, between 2 and 5 miles, between 5 and 10 miles and greater than 10 miles. That data is depicted as the green dots on Figure 9. Each dot represents the proportion of visitors making a (round) trip walk of a particular distance or more. So for the Lake District data we see 100% of visitors walking at least 0 miles, 90% walking at least 2 miles, 55% walking at least 5 miles and 13% at least 10 miles.

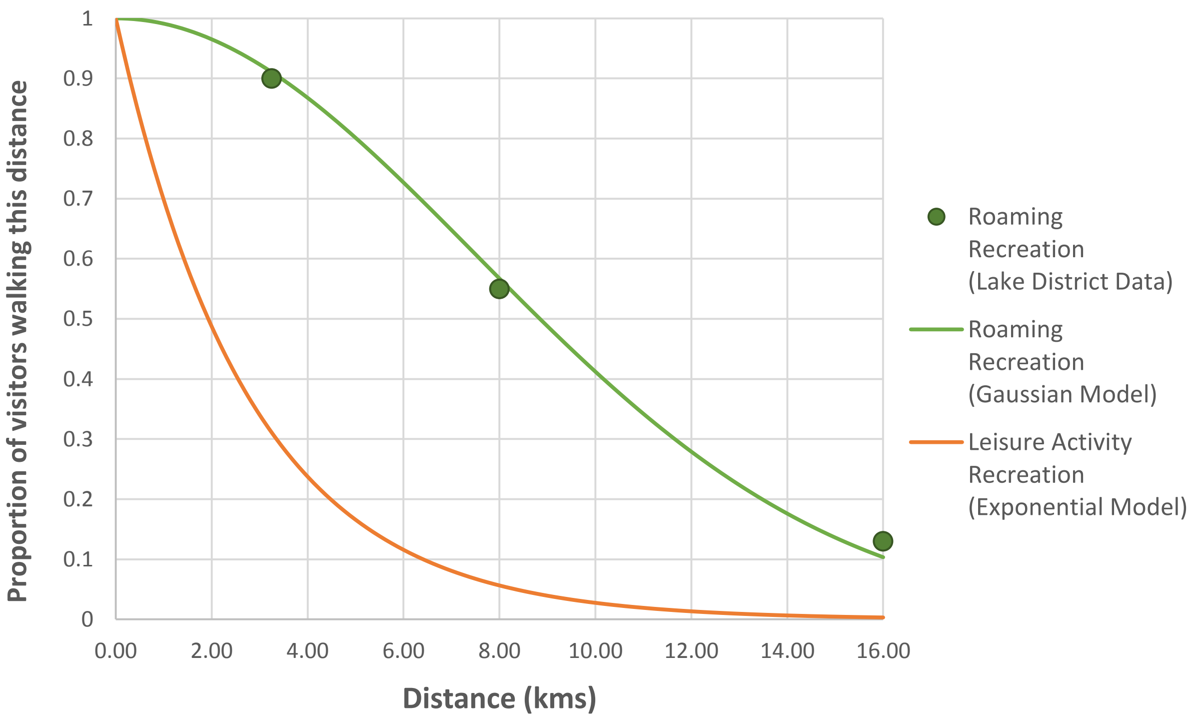


Figure 9: Distribution of (round trip) travel distances for different forms of recreational activity

As shown in Figure 9, we find that a reasonably accurate fit to the data is provided by using a Gaussian (Normal) distribution (with most visitors walking average distances, and smaller proportions of visitors taking very long and very short walks). This provides us with a model which predicts the proportion of roaming recreationists that will take trips of different distances. To illustrate, imagine we have an access point that we expect to be visited by 100 roaming recreationists. Of those 100, we would expect 90 to make trips that took them at least 2 miles from that access point, 55 who will travel at least 5 miles and 13 who will travel at least 10 miles. Our fitted line effectively traces out the distance decay function for penetration of recreational walkers through a paths network from a particular access point.

Notice that to use this distance decay function for Dartmoor we have to assume that walkers visiting Dartmoor behave similarly to walkers visiting the Lake District. We have no way of verifying that assumption though we do note that the Lake District data includes holiday makers as well as local day visitors that are the focus of our project.

We contend that the distance decay function for leisure-activity recreation will be different to that of roaming recreation. Again, there is no actual data to support that contention or to indicate the appropriate form of distance decay for this alternative form of recreation. Accordingly, we proceed by considering the walking done in pursuit of leisure-activity recreation as being like 'travel'; that is to say, we imagine people transport themselves to an access point in proximity of the location in which they wish to undertake their leisure activity and that their walk to that location through the paths network can be treated like an extra element of travel.

Again rather limited evidence exists to understand how far individuals are prepared to travel on foot in order to enjoy leisure activities in the UK. Instead, we took information from a US study by Yang and Diez-Roux (2012). Drawing on data from the US National Household Travel Survey from 2008-09 the Yang and Diez-Roux study developed travel distance distributions for trips for different purposes. The authors found that the distances of walking in order to access recreation were substantially longer than for other purposes and fitting their data to an exponential distribution report a distance decay function for such trips that is replicated in Figure 9.[4]

[4] The exponential function fitted by Yang and Diez-Roux (2012) has a coefficient of 1.15. That distance decay function refers to one-way distances. To be compatible with the distance decay function for the distribution of round-trip distances for roaming recreation, the curve in Figure 9 is adjusted to include the distance of the return journey.

As might be expected, the distances walked for leisure-activity recreation tend to be shorter than for recreation where walking itself is the focus of the activity. Indeed, according to the assumptions underpinning Figure 9, the median distance walked for the purposes of leisure-activity recreation is a little less than 2km, while that for roaming recreation is nearer 9km.

3.3.3 Forecasting Route Choice

So far we have determined that approximately 81% of the visitors arriving at a recreation access point on Dartmoor might be pursuing roaming recreation and 19% leisure-activity recreation. Moreover, the assumptions laid out in the last section lead us to the distribution of walking distances we might expect to see from recreationists of each type. Accordingly, if the ORVal model were, for example, to predict 100 visitors arriving at a particular access point over some particular time period, then we could estimate that 81 of those will be roaming recreationists and 19 leisure-activity recreationists. Of the 81 roaming recreationists we can estimate that at least 78 will make round-trips walks of 2 km or more, 46 of 8km or more and 8 of 16km or more. Of the 19 leisure-activity recreationist the equivalent figures are 9 visitors walking 2km or more, 1 taking an 8km walk and none taking a 16km walk. Indeed, given our assumptions we can plot out through the paths network of Dartmoor how many people we might expect to walk as far as that location from an access point.

Applying those assumed distance decays to our predictions of visitors accessing the National Park from certain locations allows us to build up estimates of the intensity of use of different locations across the Dartmoor landscape. Since our eventual focus will concern possible levels of disturbance caused by recreation on Dartmoor, we choose to illustrate footfall intensity by examining activity on the busiest days of the year. To that end we extract the ORVal visit predictions for a weekend day in the height of summer. We assume that visitation across the day is not uniform and that dividing the daily visits by 5 will give us a rough idea of the number of arrivals at each access point during a peak hour of that day.

The left hand panel of Figure 10 shows how visits from each access point can be traced through a path network where the red dots along the path are set at 50m intervals and the size of those dots indicates the number of individuals per hour expected to pass that point during the period of peak activity.

Notice from that left hand panel of Figure 10 that a complexity arises where two paths join. In order to develop an algorithm that mimics recreation behaviour we need some way of making choices regarding how many visitors decide to take each path when arriving at a junction in the network. In this work, we make the assumption that at a junction walkers are most likely to pursue a path that takes them on in the same direction as they approached the junction and ascribe such paths the weight 1. Likewise we assume that walkers are least likely to take a path which takes them back exactly the way that they have just come and ascribe such a path the weight 0. For paths leaving a junction at other angles we choose weights in between those two extremes using the weighting function shown in Figure 11. Here a path leaving the junction at a 45° angle from the direction of arrival is allotted a weight of 0.9, while one leaving at right angles to the arrival direction receives a weight of 0.5.

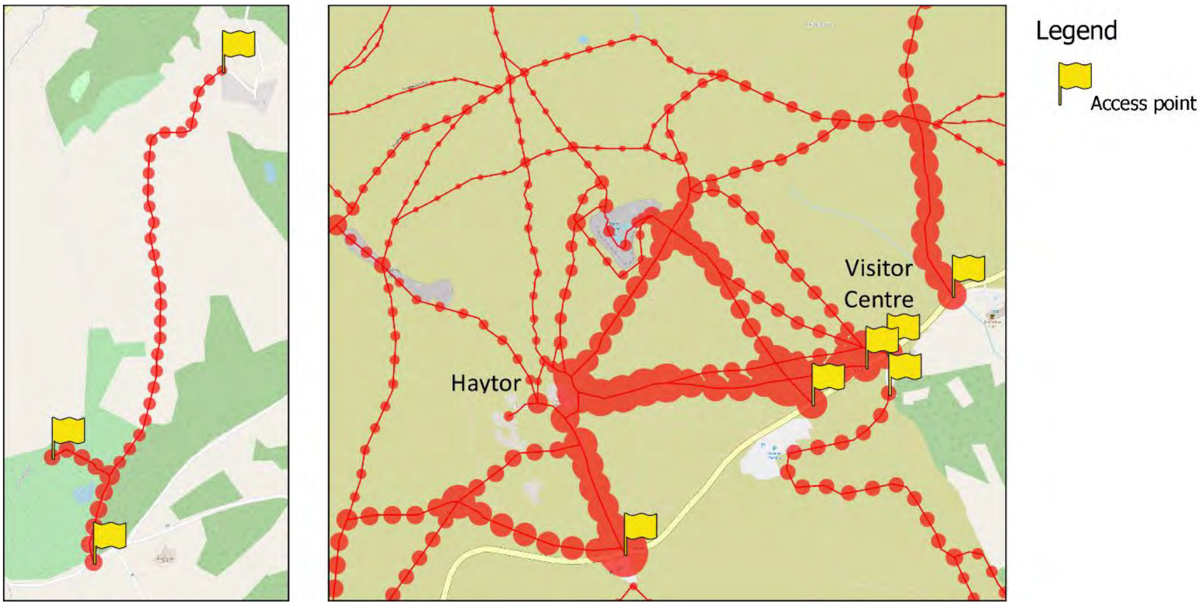


Figure 10: Examples of predictions of footfall intensity along two path networks on Dartmoor

In order to predict the choices of visitors arising at a junction, we first use the function in Figure 11 to assign a weight to each path leaving that junction, then sum those to arrive at a total weight. Visitors are ascribed to each path in exact proportion to the ratio of a path's weight to that sum of weights. The right hand panel of Figure 10 illustrates how the distance decay and route choice algorithms combine to distribute visitors through the complex network of interconnected paths around Haytor.

3.3.4 Predictions of Changing Intensity of Footfall across Dartmoor

When brought together the steps taken in predicting footfall across Dartmoor entail;

i. Predict the spatial distribution of population using ONS estimates refined to LSOAs in the 8 neighbouring LADs through interrogation of local plans.
ii. Use the ORVal model, calibrated to information on visitation to Dartmoor recreation sites, to predict the number of adults from the population arriving at access points to the National Park on a particular day
iii. Estimate arrivals on a particular hour of that day then apply the distance decay and route choice algorithms to predict how those visitors disperse across Dartmoor and hence the intensity of footfall across the National Park.

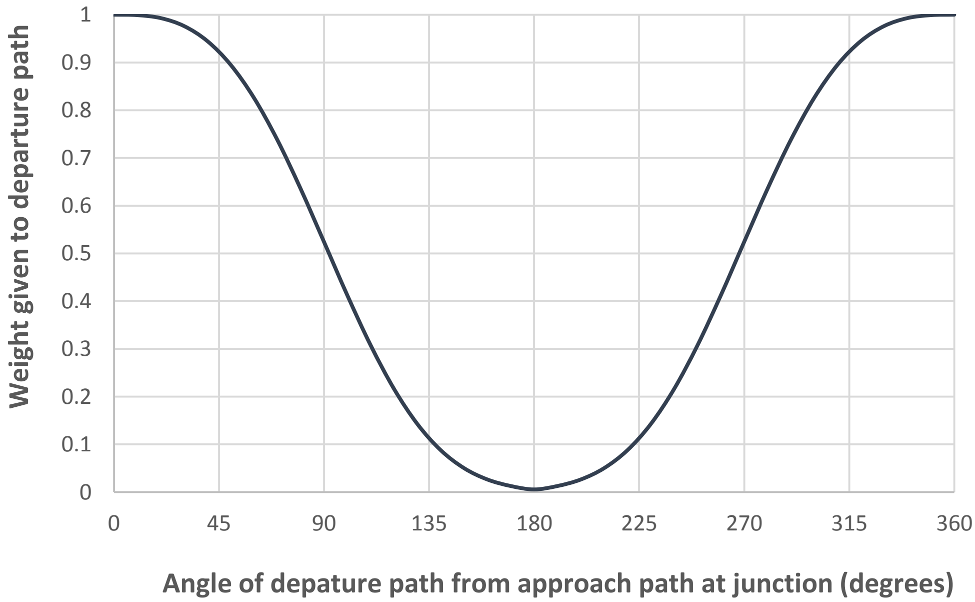


Figure 11: Weighting used to attribute likelihoods to choice of departure path from junction

Figure 12 provides an illustration of footfall intensity estimates made for the 2019 population predictions at a time of peak activity on a summer weekend.

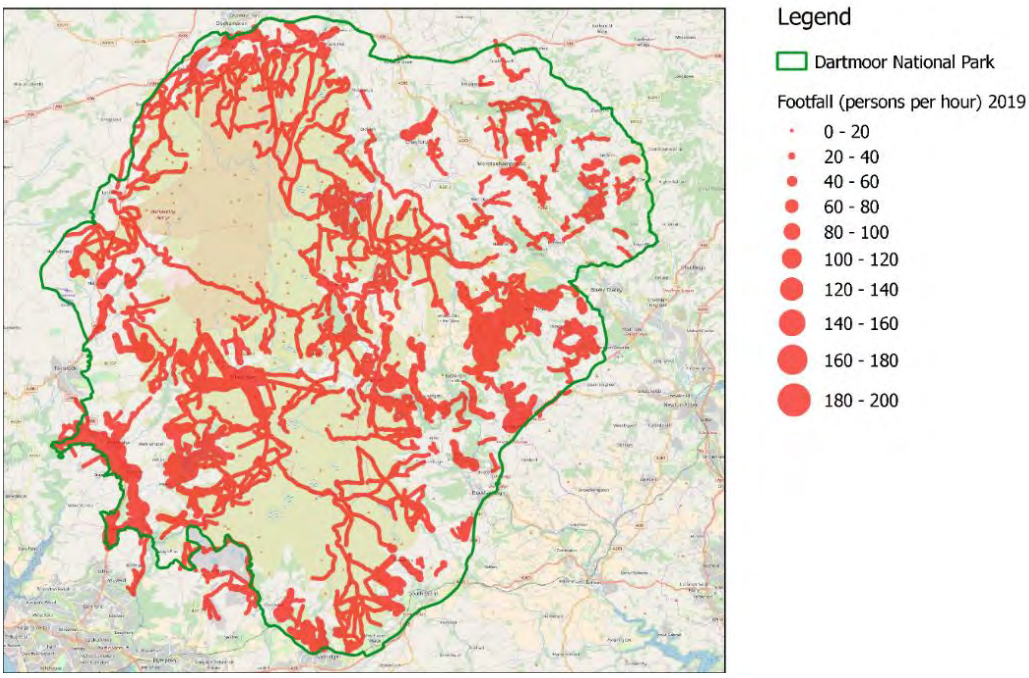


Figure 12. Predictions of peak hourly (summer weekend) footfall across Dartmoor in 2019.

While it is difficult to summarise the detail of these spatialized predictions, it is clear from Figure 12 that a number of high intensity footfall areas exist across the National Park. On the Figure we pick out those around Haytor, Princetown and Burrator, though other areas of intensive use are also evident.

Applying the same methods to the populations expected in future years allows us to make predictions as to how footfall intensity might increase across the National Park over time. Those predictions of growth in footfall are illustrated in Figure 13. Be aware that the scale of the size of symbols illustrated footfall has changed from that in Figure 12 which shows absolute levels in 2019.

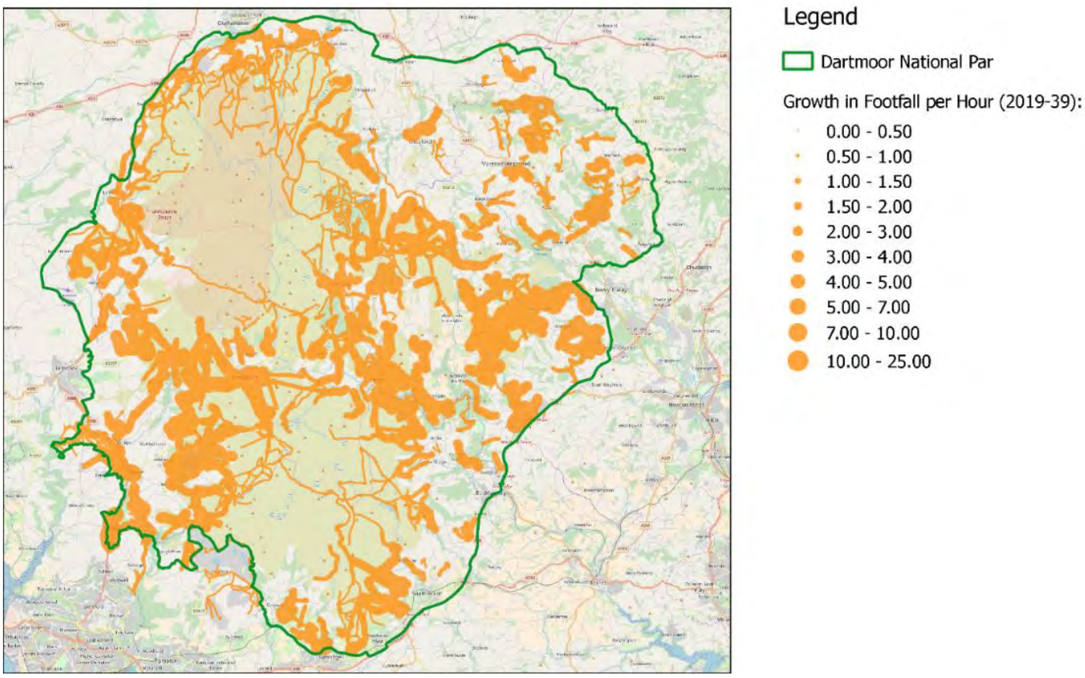


Figure 13. Growth in footfall (increase in persons per hour at peak times) across Dartmoor from 2019 to 2039.

From Figure 13 it is clear that fairly substantial increases in footfall intensity are expected in several locations across the National Park with peak increases of around 25 persons per hour at peak times. Not surprisingly, the locations attracting the largest increases in footfall are those that are also currently most attractive to visitors. The prediction algorithms also allow us to disaggregate the growth in footfall intensity by the local authority area from which visits arose. Figure 14 to Figure 21 present those visualisations for the 8 different LADs in the Dartmoor region. These maps illustrate also that the growth in footfall intensity shows spatial differences between the LADs. Growth in footfall tends to be greatest in areas within the National Park that fall within or near the corresponding LAD, with for example Teignbridge contributing most significantly to footfall growth in the east of Dartmoor, and Plymouth to the southwest of Dartmoor. As might be expected, LADs more distant from Dartmoor, such as East Devon and Mid Devon, contribute relatively little to the growth in footfall, and change is more evenly spread across the National Park.

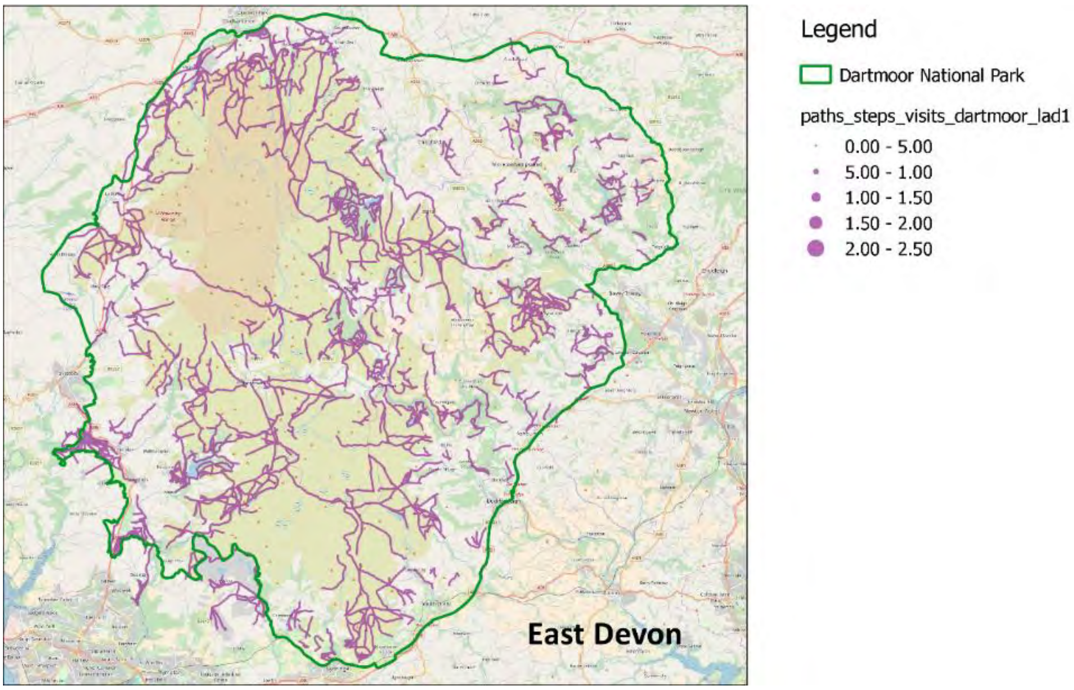


Figure 14. Predicted contribution to growth in peak hourly footfall from East Devon (2019-2039)

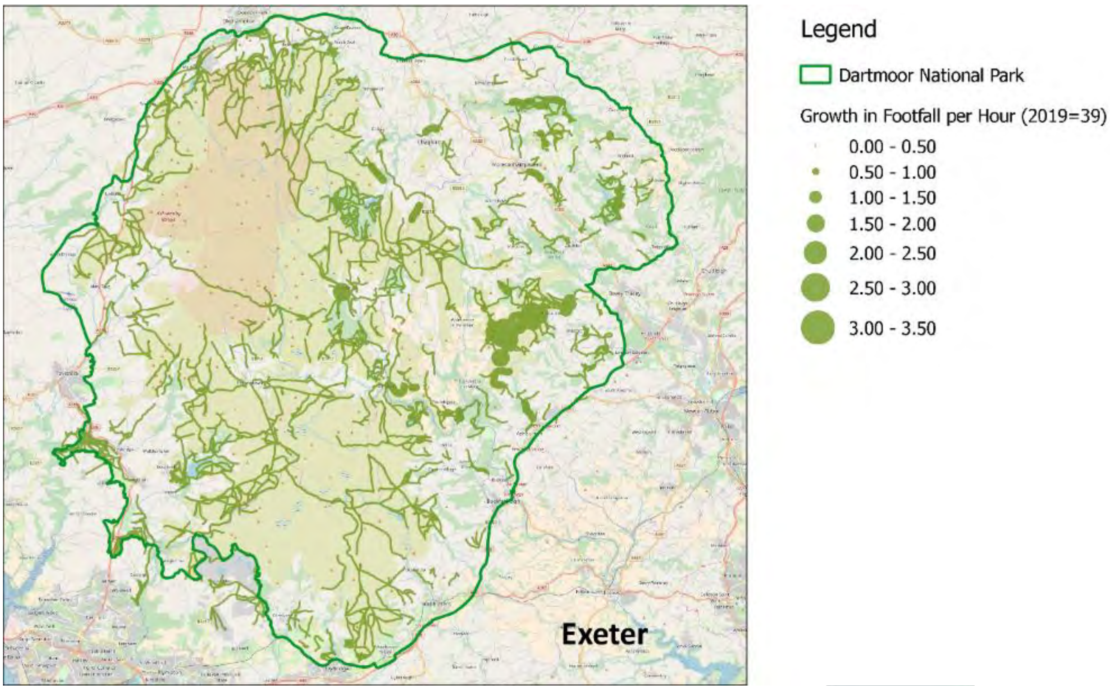


Figure 15. Predicted contribution to growth in peak hourly footfall from Exeter (2019-2039)

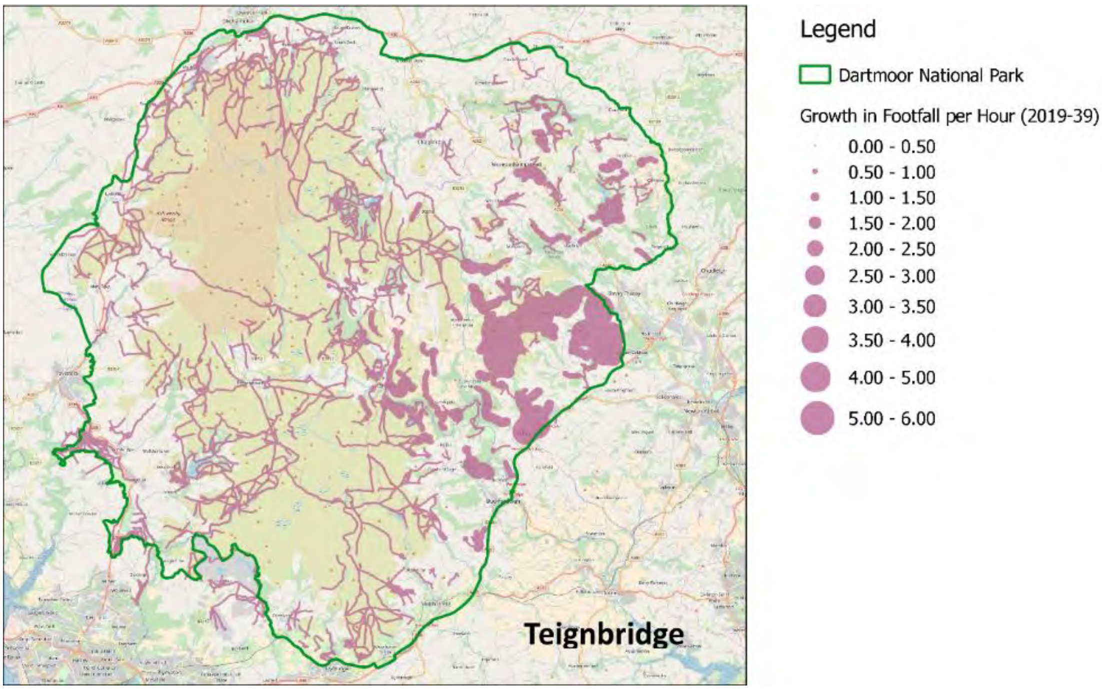


Figure 16. Predicted contribution to growth in peak hourly footfall from Teignbridge (2019-39)

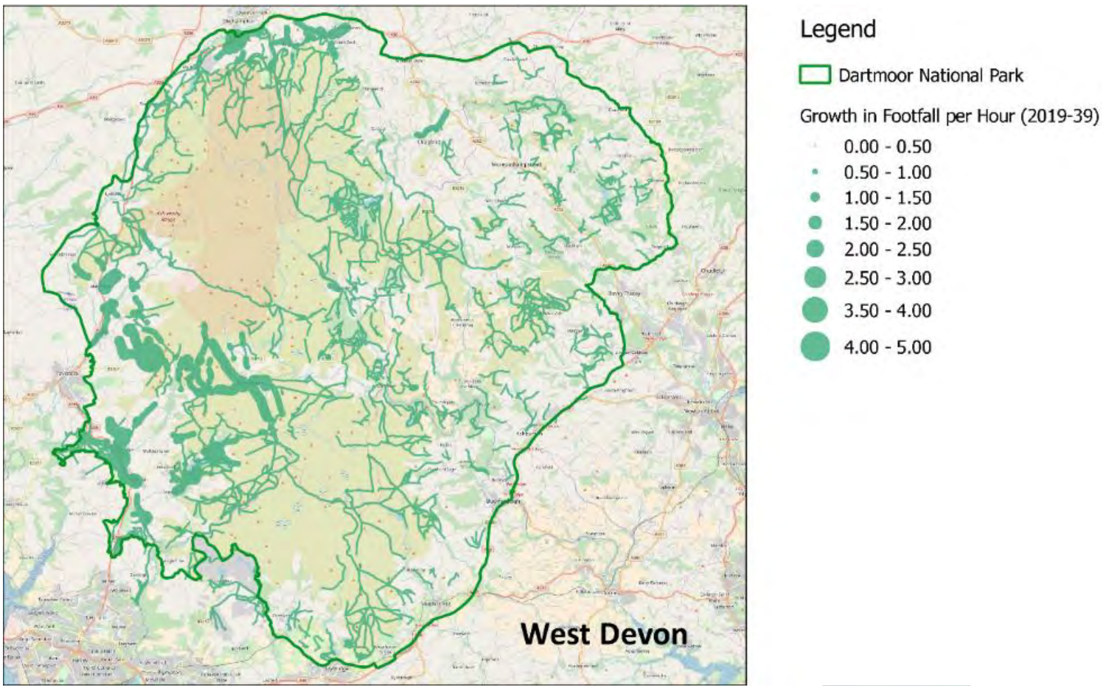


Figure 17. Predicted contribution to growth in peak hourly footfall from West Devon (2019-2039)

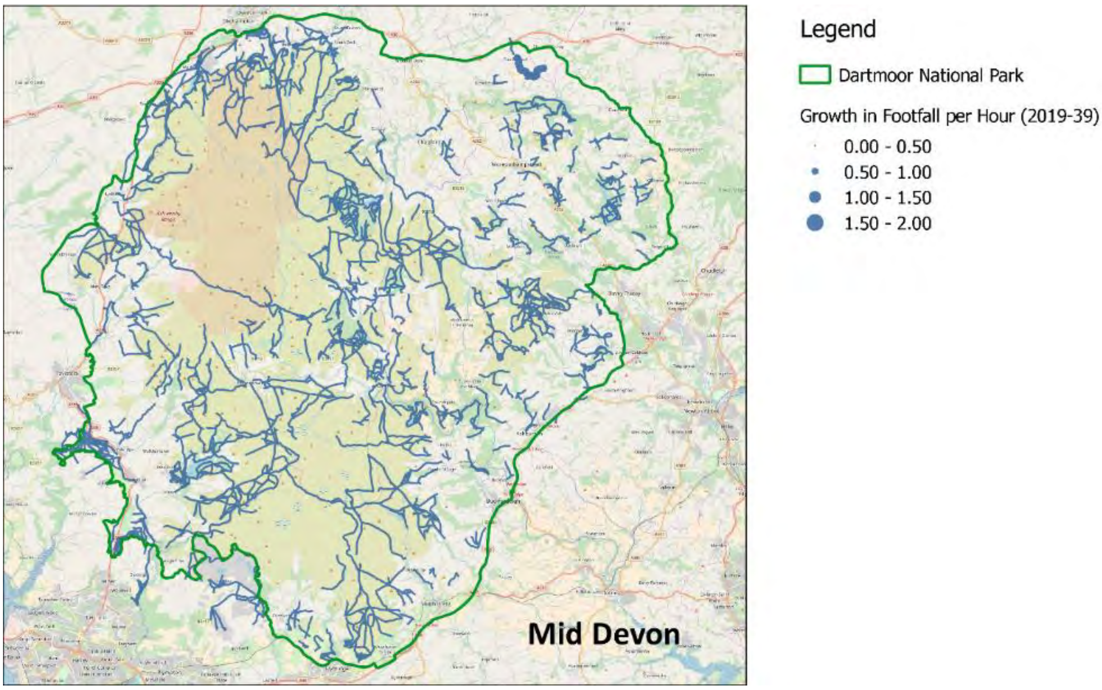


Figure 18. Predicted contribution to growth in peak hourly footfall from Mid Devon (2019-2039)

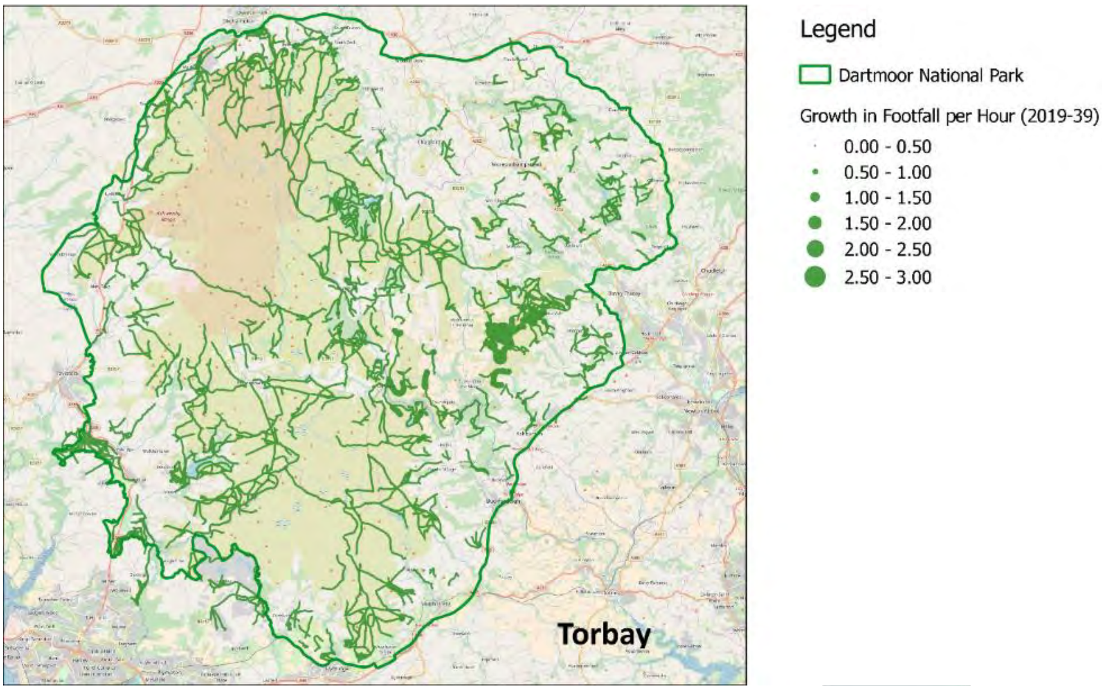


Figure 19. Predicted contribution to growth in peak hourly footfall from Torbay (2019-2039)

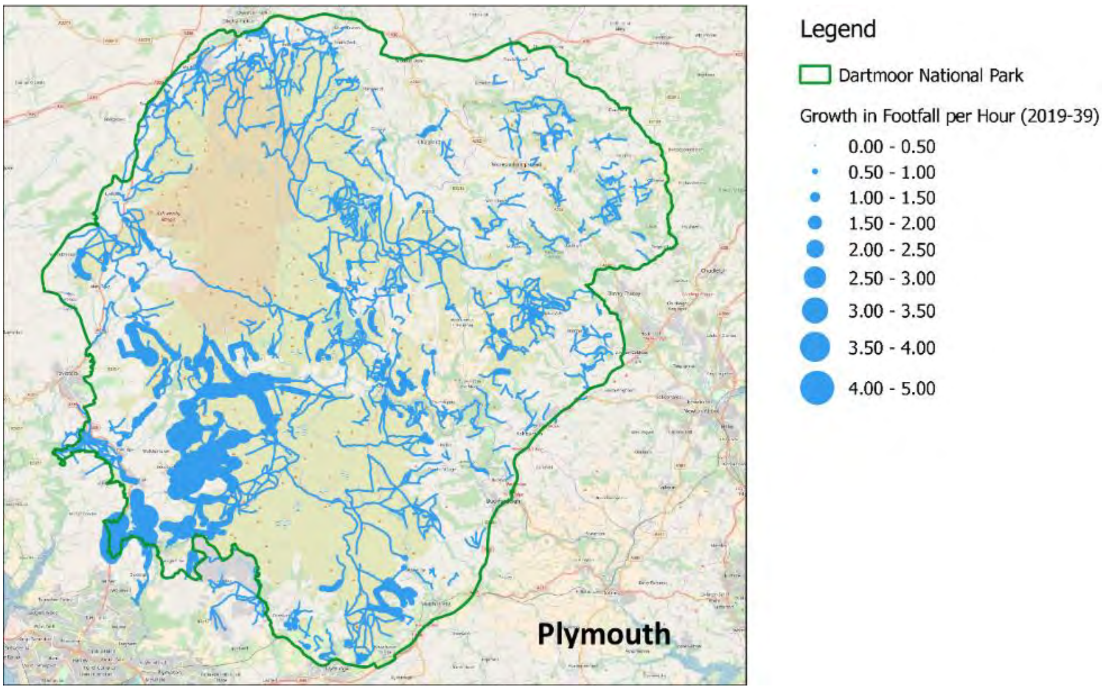


Figure 20. Predicted contribution to growth in peak hourly footfall from Plymouth (2019-2039)

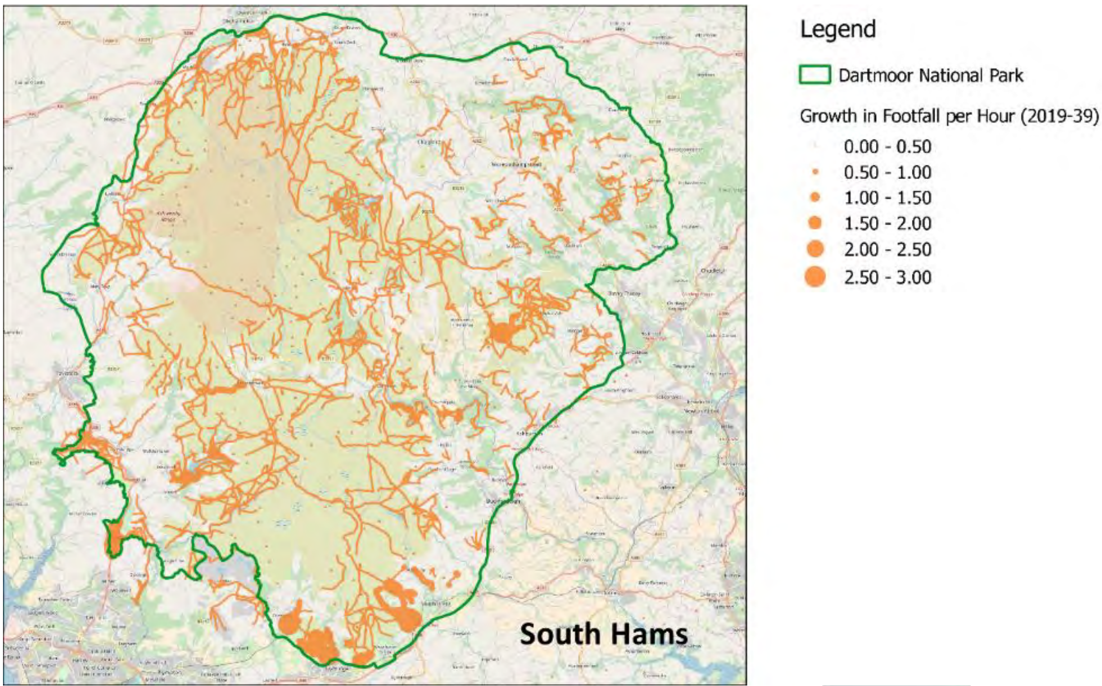


Figure 21. Predicted contribution to growth in peak hourly footfall from South Hams (2019-2039)

4 BENEFITS OF DARTMOOR

Recreation on Dartmoor is of key importance directly contributing to the second statutory purpose for National Parks (Environment Act 1995); *"promoting opportunities for the understanding and enjoyment of the special qualities of those areas"*. In this section we conduct a detailed analysis of the benefits of both current and future recreation levels, focusing on the welfare benefits and activity benefits of Dartmoor visits. This analysis is focused on day visits from visitors from Local Authority Districts (LADs).

4.1 WELFARE BENEFITS

As a focus of recreation activity, Dartmoor is a source of enjoyment for the many visitors who travel to the National Park each year. In social cost-benefit analysis (as prescribed, for example, in the Treasury Greenbook) the way in which that enjoyment can be quantified is by translating it into a measure of Willingness to Pay (WTP). In this particular context, WTP measures the maximum amount of money that an individual would be prepared to give up in order to ensure that they could visit a recreation site on Dartmoor.

For clarity, WTP is not to be confused with the travel cost of getting to a recreation site. Rather one can think of the monetary amount that a visitor would think equivalent to the experience of enjoying time at the recreation site. To have that experience they must travel to and from the site; that is to say, incur a travel cost. Roughly speaking, WTP for the recreation site will be the difference between the value of the onsite experience and the cost of being able to enjoy that experience. If we assume that the value of the onsite experience is similar across individuals then it follows that WTP is likely to be higher for those who live in or near Dartmoor since they have low costs of enjoying that experience and progressively lower for those living at greater distances.

While the term can be a little confusing, in economics this WTP measure of benefits is often simply referred to as a measure of welfare and we follows that convention here.

As explained in Section 3.1.3 the basic building block of the ORVal model is the estimation of a function which quantifies the level of enjoyment (or in economic terms, utility) that an individual realises from visiting some particular recreation site. That function includes a large number of variables including the qualities of the recreation site and, of course, the travel costs of getting to that site. While the details of the calculation are somewhat complicated (see Day and Smith, 2018) the ORVal model can be used to calculate the WTP of each adult in England for each recreation site on Dartmoor and aggregate these up either to give a total welfare value or a welfare value by LAD or LSOA.

Table 6 provides estimates of welfare benefits derived from recreational use of Dartmoor for the residents of each of the eight LADs in the National Park's neighbourhood. The welfare values are quoted in 2016 prices and provide the annual total for all residents and the welfare value per head of population in that LAD. In addition Table 6 shows how these welfare values are predicted to change from 2019 to 2039.

Table 6: Welfare predictions for Dartmoor recreation day visits from neighbouring Local Authority Districts for 2019 population estimates

Region	2019 Welfare (£2016)		2039 Welfare (£2016)		Change in annual Welfare 2019-39 (£2016)
	Total	Per Head	Total	Per Head	
East Devon	970,758	8.18	1,200,070	8.77	229,313
Exeter	1,807,818	16.60	2,051,361	16.61	243,543
Teignbridge	6,417,551	58.43	7,116,188	56.97	698,637
West Devon	4,728,658	95.59	5,025,164	93.10	296,506
Mid Devon	928,539	14.03	1,017,552	13.84	89,013
Torbay	2,050,026	18.17	2,267,994	18.17	217,968
Plymouth	5,351,929	24.10	5,803,982	23.99	452,053
South Hams	3,376,965	46.41	3,631,514	45.96	254,548
Total:	25,634,263		28,115,865		2,481,582

From Table 6, the headline figures are that Dartmoor currently provides an estimated £25.6 million of welfare benefits to the residents of the 8 neighbouring LADs each year and that as a result of population increases that number will rise annually. By 2039, welfare benefit is predicted to have risen from £25.6 million to £28.1 million; an increase of annual welfare benefit of £2.5 million. Notice also that our expectations are fulfilled insomuch as the largest welfare values are again realised in those LADs with significant populations in and around Dartmoor including Teignbridge, Plymouth, West Devon and the South Hams.

Table 7 provides one final analysis of the welfare generated by recreation on Dartmoor. In particular it disaggregates the annual welfare flows enjoyed by the residents in each LAD by socioeconomic segment, using the 2019 predictions to illustrate.

Table 7: Welfare predictions by socioeconomic segment for 2019 population estimates

Region	Socioeconomic Segment			
	AB	C1	C2	DE
East Devon	295,569	311,363	216,902	146,924
Exeter	481,080	669,902	338,884	317,952
Teignbridge	1,964,552	1,934,168	1,496,535	1,022,295
West Devon	1,487,237	1,357,937	1,144,525	738,960
Mid Devon	258,977	265,227	249,845	154,490
Torbay	401,696	663,311	496,278	488,741
Plymouth	1,086,216	1,907,566	1,208,458	1,149,688
South Hams	1,148,914	1,014,824	751,796	461,432
Total:	7,124,240	8,124,298	5,903,223	4,480,482
	(27.8%)	(31.7%)	(23.0%)	(17.5%)

One interesting thing to note from Table 7 is that the AB socioeconomic segment make up 20.7% of the regional population (see Table 1) but enjoy a 27.8% share of the welfare benefits from Dartmoor. In contrast, the DE socioeconomic group make up 22.9% of the regional population but enjoy only 17.5% of the welfare benefits. The fact that the AB group take a relatively high proportion of the welfare benefits arises from two facts. First the statistical model underpinning the ORVal tool shows that the AB group are more likely to engage in outdoor recreation than other socioeconomic groups. Second, the AB group are more likely to have access to a car than the DE group and hence are more likely to possess the means of getting to the National Park.

4.2 ACTIVITY BENEFITS

Clearly Dartmoor is a location from which a large number of individuals gain recreational welfare. As we have seen, for many of those visitors a key element of that enjoyment is derived from the physical activity of roaming across Dartmoor's landscape. Accordingly, another benefit provided by the National Park arises from the potential health benefits of that activity.

The obesity epidemic is estimated to have cost the NHS £6.1 billion in 2014/2015, and a reduction in physical activity levels over recent decades is thought to be a substantial contributor to the problem.[5] The government has previously published a call to action to local governments and communities to tackle the issue.[6] Dartmoor National Park Authority's "Naturally Healthy" Project piloted a "green care" programme with local GPs and communities, which showed a positive effect on the mental well-being of participants (DNPA 2018). Our modelling framework allows us to expand on this and provide further insights into the magnitude of health benefits of recreational activity in the National Park, using estimates of energy or fat burned to proxy for those health effects.

In particular, our analysis of footfall allows us to make predictions regarding the levels of walking activity on Dartmoor. The calibrated ORVal model provides the base data for this, predicting the number of visitors arriving at each recreation access point each year. From that data, and continuing our assumption of 81% roaming and 19% leisure-activity recreation, we use the distance-walked distributions of Figure 9 to estimate the total distance walked by visitors to the park over the course of a year. Those estimates for all visitors and for those from each neighbouring LAD in 2019 are shown in the second column of Table 8.

The third column of Table 8 converts distance into steps by dividing by an average step length of 0.75m. The fourth column of Table 8 converts distance walked to energy expenditure used in walking by assuming the commonly applied rule of thumb that an average individual uses 0.260 KJ of energy per meter when walking

[5] Public Health England Guidance. Health matters: obesity and the food environment. *https://www.gov.uk/government/publications/health-matters-obesity-and-the-food-environment/health-matters-obesity-and-the-food-environment--2*

[6] Healthy Lives, Healthy People: A Call to Action on Obesity in England. *https://www.gov.uk/government/publications/healthy-lives-healthy-people-a-call-to-action-on-obesity-in-england*

(LeCheminant et al, 2009). Finally we convert estimates of energy expenditure to estimates of fat burned by applying the assumption that one kg of fat represents 37,000 kJ of energy.

Table 8. Aggregate physical activity levels from predicted recreational activity on Dartmoor in 2019

Region	Distance (km)	Steps (million)	Energy Expenditure (kJ)	Fat Burned (kg)
England	18,376,854	24,502	4,774,098,770	129,030
East Devon	304,121	405	79,007,079	2,135
Exeter	694,528	926	180,430,554	4,877
Teignbridge	3,267,405	4,357	848,834,744	22,941
West Devon	3,579,904	4,773	930,018,622	25,136
Mid Devon	301,920	403	78,435,513	2,120
Torbay	827,370	1,103	214,941,293	5,809
City of Plymouth	3,580,704	4,774	930,226,352	25,141
South Hams	1,686,138	2,248	438,039,519	11,839

The headline figures from Table 8 are that access Dartmoor enables recreational activity that results in the population of England burning an estimated 129,030 kg of fat each year. Just under 100,000 kg of that fat-burn is realised by residents of the local LADs. It is also worth noting that previous research has shown that, when compared to individuals at rest, physical activity increases fat oxidation in the hours after the activity was completed, therefore leading to health benefits in addition to the fat burn calculated here (Votruba et al. 2002).

Table 9 provides another take on the same data. By dividing the physical activity levels in Table 8 for visitors from each LAD by that LAD's population (both at 2019 estimates) we arrive at an approximation of the average level of physical activity undertaken on Dartmoor for each adult in each LAD. Of course, the number of visits and their levels of activity will differ across individuals in each LAD, so the figures in

Table 9 represent the activity we might expect to see from an 'average' resident of each LAD.

Table 9. Per capita physical activity levels from predicted recreational activity on Dartmoor in 2019

Region	Distance (km)	Steps	Energy Expenditure (kJ)	Fat Burned (g)
East Devon	2.56	3,417	666	18.0
Exeter	6.38	8,502	1,657	44.8
Teignbridge	29.75	39,667	7,729	208.9
West Devon	72.37	96,492	18,801	508.1
Mid Devon	4.56	6,082	1,185	32.0
Torbay	7.33	9,780	1,906	51.5
City of Plymouth	16.12	21,496	4,188	113.2
South Hams	23.17	30,900	6,021	162.7

A commonly stated health objective is that individuals should attempt to walk 10,000 steps a day. From Table 9 we see that for LADs in or bordering the National Park, Dartmoor forms the backdrop for several days' worth of such levels of activity. Residents of West Devon, for example, will on average achieve 10 days' worth of their target number of daily steps each year while recreating on Dartmoor.

One thing to note about the figures in Table 8 and Table 9 is that we cannot assume that without Dartmoor the physical activity would not instead be enjoyed at some other outdoor recreation site. One reasonably defensible assumption is that the physical activity benefits of trips to Dartmoor that are 'new' (i.e. where the individual would not have taken an outdoor recreation trip instead of the trip to Dartmoor) are wholly attributable to the existence of the recreation facilities of the National Park. From Table 3 we see that ORVal estimates the number of new visits to be around 30% of total visits, such that a good lower bound estimate of physical activity benefits would be 30% of the figures in Table 8 and Table 9.

Finally, Table 10 identifies the physical benefits that we expect to be realised by new residents of the Dartmoor hinterland arriving in the area in the period 2019 to 2039. Observe that these estimates differ from those in Table 9 insomuch as these new populations are expected to live in particular locations that may differ in terms of their proximity to Dartmoor compared with the general population of each LAD in 2019. Taking East Devon as an example, the expected increase in population in that

LAD will tend to focus on the new town of Cranbrook which is located relatively close to Dartmoor compared to the rest of the geographical area of that LAD. Accordingly, we see more visits and more physical activity from these new residents (e.g. 36.9 grams of fat burned per year on Dartmoor per person) than we do from the current population (e.g. 18 grams of fat burned per year on Dartmoor per person). In other words, the average Dartmoor activity levels by residents of the East Devon LAD is expected to increase because the development of Cranbrook is increasing the amount of East Devon housing which lies geographically close to Dartmoor. This increases the proportion of East Devon residents choosing to visit Dartmoor, and therefore increases the average level of Dartmoor activity per head for the East Devon LAD.

Table 10: Physical activity benefits per year per adult for predicted new populations in Dartmoor hinterland

	Population Increase 2019 to 2039	Distance (km)	Steps	Energy (kJ)	Fat (g)
East Devon	18,167	5.26	7,009	1,366	36.9
Exeter	14,594	7.67	10,232	1,994	53.9
Teignbridge	15,087	24.25	32,327	6,299	170.2
West Devon	4,509	50.87	67,832	13,217	357.2
Mid Devon	7,324	5.11	6,810	1,327	35.9
Torbay	12,012	8.83	11,776	2,294	62.0
City of Plymouth	19,809	17.13	22,834	4,449	120.2
South Hams	6,266	24.45	32,607	6,353	171.7

5 COSTS TO DARTMOOR

The previous sections of this report covered current and future levels of recreation, and outlined the welfare and activity benefits which are derived from recreation on Dartmoor. In this section, we cover a selection of the negative impacts which recreational activity can have on Dartmoor.

The first impact we consider is path erosion. This was selected as a focal area as previous sections of the report established that the majority of Dartmoor recreational activity is in the form of walking and running, and because our models show a substantial predicted increase in footfall levels on Dartmoor paths. Understanding sites sensitive to path erosion can help Dartmoor National Park Authority prioritise appropriate sites for monitoring, funding allocation and management.

The second impact we consider is impacts to wildlife through human visitation. The Environment Act 1995 states two purposes for National Parks[7];

- *" conserving and enhancing the natural beauty, wildlife and cultural heritage and*
- *promoting opportunities for the understanding and enjoyment of the special qualities of those areas".*

As conserving and enhancing the natural beauty and wildlife is a key statutory aim for National Parks, it is of key importance to understand the potential impacts of recreational activity on conservation. Dartmoor is home to a wide range of species, with numerous species of national and international conservation importance. In this section on impact to wildlife we assess the impacts of human visitation on key Dartmoor species.

It is important to note that a range of other potential impacts of recreation were not considered in this report due to limitations in time and expertise. Examples include the impacts of increased recreational activity on cultural heritage (e.g. archaeological sites), as well as other anthropological impacts such as anti-social behaviour and increased pressure on infrastructure and park services. Therefore, in addition to the information presented in this report, a wider range of positive and negative impacts would need to be taken into consideration in any comprehensive management and policy decision-making.

---

[7] Environment Act 1995. Part III National Parks. Section 61.

5.1 PATH EROSION

Increasing recreation on Dartmoor has the potential to contribute to increased levels of path erosion. Walking through Dartmoor can lead to increased erosion first through the mechanical action of walking boots damaging vegetation and churning up plants and soil. A second impact that walkers have on paths is through compaction of the top soil. Compaction reduces the soils ability to absorb water encouraging the development of puddles along paths and potentially altering the courses of water flow. The consequences of these impacts are greatly exacerbated by rainfall. Standing water causes walkers to deviate from the original path leading to path-widening. In addition, with heavy rainfall especially on paths with steep gradients water flow can result in 'gullying'.

Numerous studies have been undertaken to establish the relationship between recreational use of paths and erosion. One method through which that relationship has been studied is through randomised controlled trials in which similar plots are subjected to different levels of use as measured by the number of walking 'passes' over that plot. Examples of experimental studies include that by Roovers et al (2004) who studied common forest and heath communities in Central Belgium and found that site structure and vegetation were already affected by low intensities of trampling, while vegetation recovery during the first year after trampling was limited in most plant communities. Another study by Korkanç (2014) in Aladag Mountains Natural Park in Turkey found that after 500 passes, soil penetration resistance of topsoils significantly increased, and total porosity significantly decreased, when compared to control plots. Vegetation cover was reduced to 84% after 25 passes and to 67% after 500 passes. The study by Whinam and Chilcott (2003) in the Western Arthur Range of Tasmania found that tracks formed on experimental plots at between 100 and 500 passes per annum and that, while there was some small recovery in vegetation cover after 30 and 100 passes per annum applied for three years, there was no evidence of recovery at the 500 pass treatments. The meta-analysis of such studies carried out by Pescott and Stewart (2014) concluded that the intrinsic properties of plant communities, such as the dominant plant type (e.g. water plant vs. small flowering plant vs shrub), were the most important factors determining the response of vegetation to trampling disturbance.

Another approach to the analysis of erosion has been to use technology to monitor path networks. Somewhat closer to Dartmoor, Rodway-Dyer and Ellis (2018) use LIDAR, aerial photography and on-site measurements to study rates of erosion along the South-West Coastal Path. Their study revealed that the average loss of soil along the studied sections of the path was 9 cm over five years. Erosion was generally greatest in heathland vegetation and near paths, with evidence of footpath widening and water channelling on the footpaths exacerbating erosion. Close to sites of interest, erosion levels as high as 59 cm were recorded. Whilst this study illustrates the rates of erosion seen in the southwest in habitat types similar to Dartmoor, it does not quantitatively assess the relationship between levels of erosion and intensity of footfall.

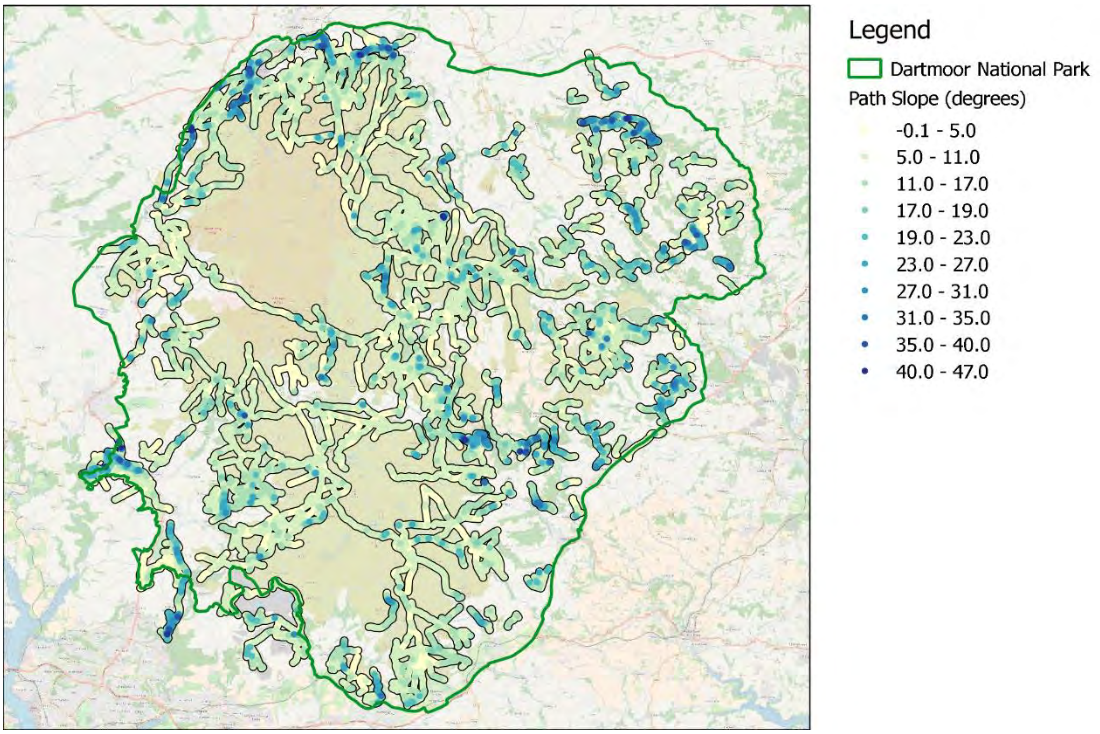


Figure 22. Locations of steep path sections at risk of erosion

The study we use to make predictions regarding rates of path erosion on Dartmoor is that by Coleman (1981) which provides a comprehensive assessment of factors impacting on footpath erosion in the Lake District. Coleman uses on the ground observations across the Lake District to relate path erosion to levels of recreational activity and characteristics of the path. The study showed that active erosion was evident on about one third of the path sites examined, and appeared on most paths with a slope of more than 17 degrees. Figure 22 provides an analysis that identifies the slope of paths across Dartmoor and hence the locations likely to be at risk of erosion from water flow.

For our purposes, the most relevant part of Coleman's study is that she provides a series of regression equations that relate number of visitor passes as well as path slope and altitude to levels of three different measures of erosion:

- Width of trampled grass along path
- Width of bare earth along path
- Depth of deepest gullying along path

The data in Coleman's study come from a sample of 485 sites along 25 different paths in the Lake District. While there are clearly significant differences between the Lake District and Dartmoor National Park (in for example geology and soils) which may affect the patterns of erosion, the regression equations provide some insight as to how increasing numbers of walkers on Dartmoor might add to levels of erosion. In particular, we take the footfall analysis from Section 3.3.4 and use the slope and height models from Figure 22 to gather the necessary variables at 50m intervals along the path network on Dartmoor. Applying the equations from Coleman (1981) allows us to make predictions regarding how the width of paths, the width of bare ground along paths and the depth of gullying might change across Dartmoor as a result of the changing levels of visitation into the future.

The results of that analysis are visualised in Figure 23 which shows how the three measures of erosion might increase from 2019 to 2039. Unsurprisingly, all three measures show the same spatial patterns with erosion risk focused on steep paths particularly in those areas experiencing the most predicted footfall.

As a rough guide to the magnitude of this potential future erosion, we took the point estimates of erosion extent and multiplied up by the 50m gap between those points on the path network. In terms of path width, therefore, we were able to calculate that by 2039 rising visitation might be responsible for an additional 74,135m^3 of vegetation being damaged by 2039 from recreation pressure widening footpaths. Likewise the model suggests that an additional 10,854 m^2 of bare ground might be exposed along the path network as a result of visitor pressure. Moreover, the predictions indicate that some 250m of path will experience increased gullying in excess of 5cm depth and 42km of path experiencing gullying of more than 1cm depth.

While a Dartmoor-specific primary study would likely be needed to properly understand the nature of erosion problems across the National Park, the analysis suggests that the magnitude of visitation increase will likely have widespread impacts on trampling of vegetation with substantial more localised erosion of paths particularly on steep sections of paths.

The top left panel of Figure 22 presents a Digital Terrain Model for Dartmoor from which measures of slope are derived and shown in the top right hand panel. Intersecting the paths network with the slope model identifies the level of slope of land over which paths pass as shown in the bottom panel of the Figure. Observe that steep sections of path can be found throughout the National Park but particularly on the Park fringes where Dartmoor rises up steeply from the surrounding countryside and also along the steep-sided river valleys that flow out of Dartmoor,

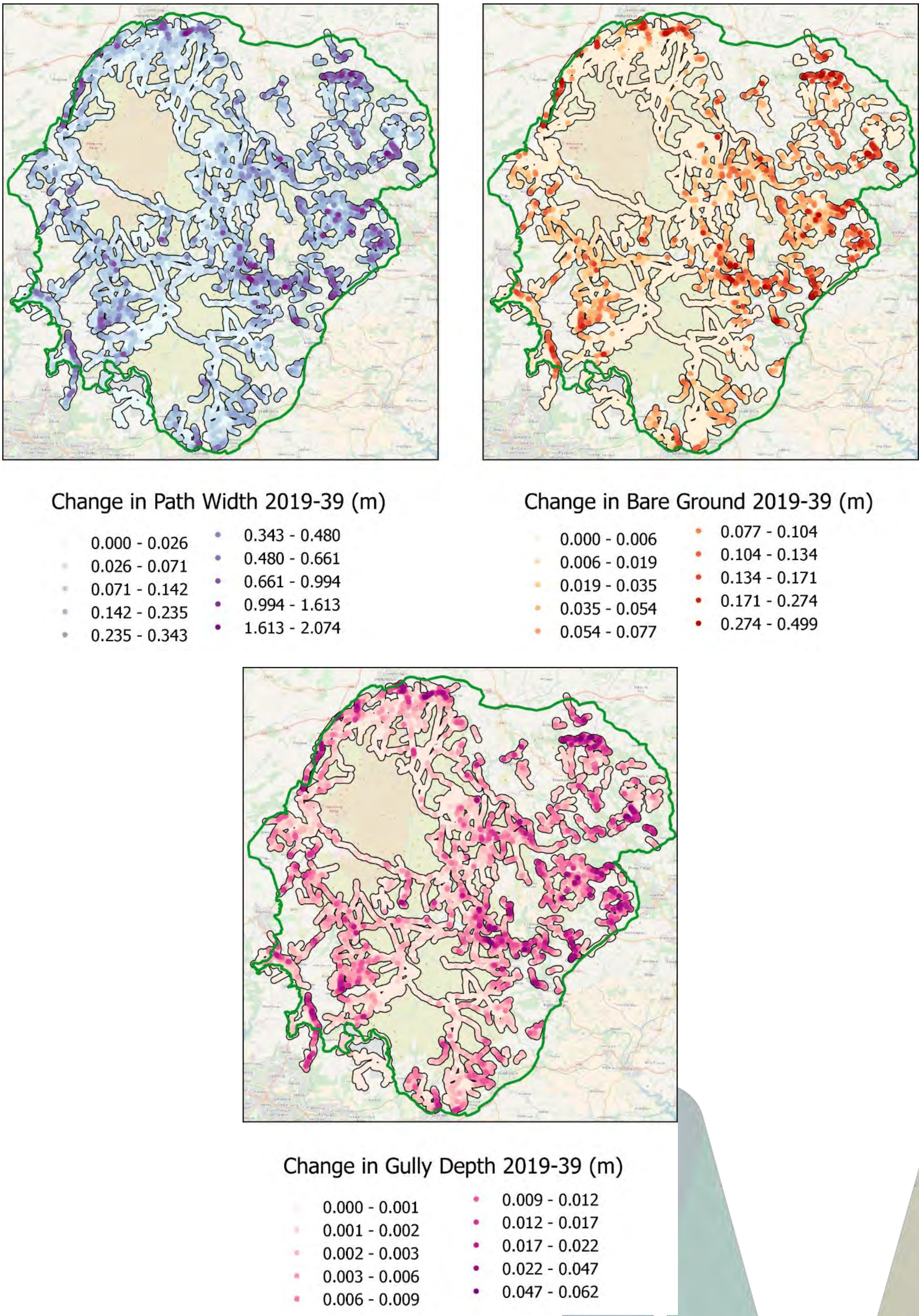


Figure 23. Predictions of locations of increasing erosion by 2039

5.2 WILDLIFE DISTURBANCE

One of the aims of this project was to understand how recreational pressures impact Dartmoor wildlife and conservation. To do so, improved understanding of the impacts of recreational activities on key Dartmoor species was needed. Here, we first provide an overview of scientific findings on the impacts of recreation on uplands and heathlands. To evaluate the potential impacts of recreation for Dartmoor specifically, this section then reports the results derived from recreation impact questionnaires with local species experts for a broad range of key Dartmoor species. Hotspot maps are shown (where known), and potential conflicts between recreational activities and key wildlife are discussed.

5.2.1 Literature overview – methodology

A literature search was conducted to provide an overview of current knowledge of recreational impacts on upland and moorland landscapes. To limit this literature search to studies most relevant to the report's objectives of assessing recreational impacts on Dartmoor, combinations of the search parameters described below were applied on the Web of Science literature database to obtain research on relevant topics and conducted in similar habitat types:

Recreational activity search terms:
"visitor", "recreation", "touris*", "footfall", "bicycl*", "cycl*", "mountainbik*", "fellwalk*", "rambl*", "walk*", "human disturbance" and "anthropogenic disturbance".
N.B. Stars (*) indicate words ending any in any letter, i.e. searching for "touris*" would find "tourist", "tourism" etc.

Impact search terms:
"impact*", "consequence*", "damage*", "degradation*" and "effect*".

Habitat search terms:
"upland", "moorland", "heathland", "oak woodland", "ancient oak woodland" and "ancient woodland"

5.2.2 Literature overview - findings

How recreation impacts on the ecology of species and landscapes is highly complex and therefore very challenging to unravel. Many studies highlight the fact that it is difficult to make generalisations about how the environment and wildlife respond to recreation pressures. Impact from recreation does not always increase proportionally as recreation increases; instead, a broad range of relationships exist between recreation levels and impacts (Monz et al. 2013). Other complicating factors need to also be considered. For instance, susceptibility to recreation impacts differs between species, intervals and timings of disturbance need to be considered alongside intensity, and interactions with other phenomena such as climate change can complicate patterns (Buckley 2013).

Furthermore, many different aspects of recreation impacts can be studied. For example, when studying the effects of anthropogenic disturbance on animals, one can measure and describe factors related to changes in individual behaviour, distribution, demography and/or population size (Gill 2007). Which factors are of interest will depend on the research or management questions. As Gill (2007) describes, impacts of recreation on species distribution will be of key importance when sites are managed to support specific wildlife, whereas if species conservation as a whole is of concern, effects on population size need to be understood.

In a set of two reviews, Marion (2016a and 2016b) assess the current literature on recreation ecology and describe mitigating management strategies. Although mostly based on US studies, these reviews provide a useful overview of current knowledge in the field. The first review provides evidence of impacts of recreation on vegetation, soils, water and wildlife (Marion 2016a), and the second review outlines five core management strategies to minimise recreation impacts; i. manage use levels, ii. modify location of use, iii. increase resource resistance, iv. modify visitor behaviour and v. close and rehabilitate the resource (Marion 2016b). Whilst not covering UK or upland landscapes, and not being written in the specific context of wildlife disturbance, these strategies could potentially be reviewed and adapted to be used to inform management decision-making strategies on Dartmoor.

In addition to the broad reviews described above, it is worth noting that a significant proportion of the research literature focuses on the impacts of recreation on birds, and several studies have reviewed that accumulated evidence. Steven et al. (2011) reviewed studies on the effects of nature-based recreation on individual, reproductive and population-level responses in birds. Out of 66 reviewed papers, they found that 88% reported negative effects of recreation on birds, with only one study (on corvids) recording positive effects (Steven et al. 2011). Similarly, a review by Showler et al. (2010) concluded that there is evidence that disturbance on foot can reduce breeding bird densities and reduce hatching and fledging success. They also mention that observational studies suggest that bird responses are stronger when dogs are present, highlighting possible additional negative effects of dog-walkers compared to regular walkers (Showler 2010).

All reviews described above form a general introduction to the wider recreation ecology literature. To illustrate studies of particular relevance to Dartmoor, we now outline findings from studies of recreation impacts which were carries out in upland, heathland, moorland and oak woodland (following the literature search methodology outlined in section 5.2.1.):

- Brambilla et al. (2004)
  Habitat type: upland/alpine cliffs
  Study overview: This study monitored ***Peregrine Falcon*** nest sites, and recorded the presence of Raven and rock climbing activity. They found that the presence of climbers lowers breeding success and productivity, which is lowered further when both Raven and rock climbers were present at a nesting cliff.
  Suggested mitigation measures: Ban or regulate climbing at and near Peregrine Falcon nesting sites.

- Botsch et al. (2017)
  Habitat type: oak woodland
  Study overview: This study experimentally tested the effects of human disturbance on bird territory settlement in oak woodlands. A total of 34 species were studied, including Wood Warbler, Lesser Spotted Woodpecker and Tree Pipit. Plots which were experimentally disturbed during the pre-breeding season (by 2-3 observers with loudspeakers with human conversation played at normal levels), showed a 15% reduction in both the numbers of territories and in species richness. This effect was not seen in long-distance migrants which arrived after the disturbance events.
  Suggested mitigation measures: This research highlights that mitigation measures should not only be restricted to the breeding season, as this study shows that relatively low levels of short-term disturbance can affect bird breeding in the pre-breeding season. Such concerns were also raised for Dartmoor (see expert opinion on Wood Warbler in the species factsheet in section 5.2.6). The authors suggest access limitations (including during the pre-breeding season), and educating the public about minimising impacts to mitigate effects.

- Finney et al. (2005)
  Habitat type: blanket bog
  Study overview: ***Golden plover*** distribution/density is affected by the presence of footpaths; the probability of recording Golden Plover decreased nearer to footpaths. It was found that after re-surfacing paths, decline in bird number was seen up to 50m from the path, whereas before resurfacing effects were seen at 200m from paths. It is important to note that from this we can derive that if (unsurfaced) paths are spaced less than 400m apart, birds such as Golden Plover could be excluded from otherwise suitable habitat. No effect on brood survival was found. See also Pearce-Higgins (2007).

Suggested mitigation measures: when footpaths are well-maintained, when clear access points are provided, and/or when visitors are encouraged not to stray from footpaths, the area and therefore extent of disturbance can be reduced. Furthermore, footpaths need to be well-spaced to ensure birds are not excluded from breeding habitats.

- Jayakody et al. (2011)
  Habitat type: upland woodland and heathland
  Study overview: Faecal diet analysis was used to compare diet of **Red Deer** at sites within 500m from a track (441 visitors/day in peak season) and 1000m+ from a track. The results suggest that human disturbance may affect the nutritional intake of Red Deer, as differences in diet composition between the disturbed and relatively undisturbed sites are shown.
  Suggested mitigation measures: Control of disturbance levels close to preferred feeding grounds in areas where high-quality food is in limited supply (although it needs to be noted that links between diet and Red Deer performance were not investigated in this study)

- Langston et al. (2007)
  Habitat type: heathland
  Study overview: It was found that failed ***Nightjar*** nests were closer to paths, access points, high-use areas and areas with higher footpath density. The total length of paths within 50m, 100m and 500m of nest sites was recorded, and in all three categories unsuccessful nests had a higher number of paths around the nest site. The increase in nest failure was largely due to increased predation rates (as eggs and nestlings are left exposed when adults are disturbed from the nest sites). It is worth noting that this study also provided some evidence of the fact that dogs disturb nest sites by recording flushing from a dog on a nest camera.
  Suggested mitigation measures: The author suggests a range of mitigation measures, including:
    - Use measures to minimise dogs straying of paths (in addition to "dogs on leads" policy). This could include managing habitat penetrability (e.g. gorse at path margins) to influence access.
    - Educating visitors
    - Access management: redirecting or closing paths, provision of access points and car parks away from breeding sites
    - Providing alternative recreation sites away from Nightjar/heathland sites

- Liley et al. (2003)
  Habitat type: heathland
  Study overview: Areas of heathland surrounded by more houses and/or urban areas supported a lower ***Nightjar*** density in this study on lowland heaths on Dorset. This reduction in density is likely to be caused by increased human visitation.
  Suggested mitigation measures: Modify/restrict visitor access, dogs on lead policy

- Mallord et al. (2007)
  Habitat type: heathland
  Study overview: Density and habitat colonisation of ***Woodlark*** is reduced by disturbance. The analysis showed that +- eight disturbance events per hour reduced the probability of habitat colonisation to less than 50%. Nest survival did not appear to be affected by distance from paths, but number of fledglings per pair *increased* at sites with high disturbance

(potentially due to reduction in competition from reduction in breeding density). Despite this increase in fledgling number, overall effects from disturbance on productivity were negative. Mallord (in the context of this study on Dorset heathland), mentions that "(…) *negative impacts are only likely to manifest themselves with large increases in overall disturbance. Although such increases are not a predicted consequence of the introduction of CRoW, they may arise from new housing developments from which heathlands in southern England are often under threat."*

Suggested mitigation measures: The creation of suitable habitats in relatively undisturbed areas, to mitigate for the reduction in available breeding sites caused by increased disturbance in otherwise suitable habitats

- Murison et al. (2007)
  Habitat type: heathland
  Study overview: This study of ***Dartford Warbler*** found that in heather territories, the start date of first broods increases as disturbance increases (effects were not seen for territories with gorse). This results in reduced productivity, as birds are less likely to fledge and fewer successful broods can be raised. Although not measured explicitly, the authors suggest that dogs may be a main factor in causing this reduction in breeding productivity. Analyses showed that approximate 13-16 visitors per hour in a territory would prevent multiple broods.
  Suggested mitigation measures:
    - Ensure dogs are kept on leads
    - control visitor access through access restrictions/path diversions
    - encourage gorse vegetation in heather territories to provide cover and prevent access to heather from paths

- Pearce-Higgins et al. (2007)
  Habitat type: blanket bog
  Study overview: Survey at the same site as Finney et al. (2005) and second site with lower numbers of visitors. Found that ***Golden Plover*** did not avoid areas near paths at the quieter site. ***Dunlin*** was also studied, and although trends were similar to those in Golden Plover (increase in numbers near footpath after re-surfacing), but low sample sizes meant that statistical significance was not shown. The study concludes that situations where visitor pressures will impact uplands waders will be rare, and that birds are only likely to be (partially) excluded from habitats at sites where path quality is poor and visitor pressure is "greater than at least 30 visitors per weekend day".
  Suggested mitigation measures: see Finney et al (2005) above

- Rouifed et al. (2014)
  Habitat type: both upland and lowland sites
  Study overview: Levels of human visitation and distance from roads (along with a range of other factors) were compared for plots with and without ***Japanese Knotweed***. Statistical models were used to understand which factors predict the presence of Japanese Knotweed, and it was found that "*for the upland plots, a shift from low frequentation to inter-mediate or similarly from intermediate to high frequentation by humans increased more than four times the probability of encountering knotweeds*". In contrast to lowland areas, the study showed that in uplands only the anthropogenic factors predicted the presence of knotweed, leading the

authors to conclude that the spread of knotweed in upland areas is mostly linked to anthropogenic activities.

Management suggestions: When surveying for the presence of Japanese Knotweed, prioritise areas where invasion risk is likely higher (i.e. near roads and sites with high visitor levels)

- Sibbald et al. (2011):

  Habitat type: upland heathland, grassland and woodland

  Study overview: This GPS tracking study compared behaviour of ***Red Deer*** on busy days (Sunday, mean of 204 walkers per day counted on main track) and quiet days (Wednesdays, mean of 49 walkers per day counted on main track) The study found that on busy days, the distance travelled by stags is higher, and individuals stay further from tracks. These effects were shown to last into the night despite the tracks being practically undisturbed at night. The study discussed that this disturbance could affect for example feeding behaviours and food intake, and physiological stress levels, but such factors were not investigated in this study.

  Suggested mitigation measures: none discussed

- Vangansbeke et al. (2017)

  Habitat type: pine plantation on former heathland

  Study overview: Recreational pressures on forest footpaths were recorded, as well as the distribution of seven species (***Crested Tit, Coal Tit, Nightjar, Common Lizard, Northern Dune Tiger Beetle, Grayling and Small Heath***). Statistical modelling was used to determine whether recreation showed a negative relationship with species distribution. Negative effects were shown for Coal Tit, Small Heath and Grayling, and vulnerability to recreation was shown to differ between different forest patches. Different hypothetical scenarios of equal amounts of visitor increase were explored, and it was shown that a land-sparing approach (where total visitor increase was not spread equally across all sites, but rather, visitor pressure was reduced in vulnerable sites, and increased more strongly at the least vulnerable sites) reduced the negative effects of increased visitor pressure. The authors note that while no negative effects on distribution were shown for the other species, past effects or other negative recreation impacts may be affecting those species.

  Suggested mitigation measures: A land-sparing approach, where (increases in) recreational activities are avoided in priority wildlife areas, could aid wildlife conservation.

- Yalden (1992)

  Habitat type: shores of upland reservoir

  Study overview: This relatively descriptive study showed that fewer Sandpiper territories were present at busy sections of shore, and that the Sandpiper presence on certain, but not all, reservoir shores showed a negative relationship with the number of anglers present. It was noted that birds flew of when a human approached within 27, and that birds with chicks are behaviourally disturbed (start alarm-calling) at distances of 75m.

  Suggested mitigation measures: The author suggest that access restrictions, as well as the provision of nearby retreat sites with low levels of recreation could help reduce conflict between recreation and breeding birds.

It is worth noting that although literature search terms (section 5.2.1) were not targeted to birds, most results covered the effects of recreation on birds. This suggest a possible research bias in the animal groups for which studies into recreation impacts on wildlife are carried out. This literature search was not comprehensive and restricted in the used search terms, and broader literature searches, particularly in habitat types not covered here, may therefore show further evidence of recreation impacts on a wider range of species.

A local study of interest and of direct relevance to Dartmoor is the 2006 Breeding Bird Survey of the Dartmoor Training Area, which includes a discussion on the effects of paths on bird distributions. It was found that path presence did not appear to affect Meadow Pipit, Skylark and Wheatear distributions, but that Stonechat and Grey Wagtail showed a negative relationship with path presence. A positive relationship was shown for Pied Wagtail.

From the literature reviewed above, it is clear that studies on recreational impacts are limited to very few bird species and habitat types, and that quantitative evidence on established levels of footfall and subsequent population consequences is lacking. In the next section we sought to complement this literature overview with local expert judgement in order to obtain qualitative Dartmoor-specific insights on (potential) recreation impacts for key species of interest. A range of potential mitigation measures for Dartmoor's species and habitats are outlined also.

5.2.3 Impacts on key Dartmoor species - methodology

To understand how recreational activities impact key species on Dartmoor, local experts on the species of interest were contacted to share their knowledge, captured through a questionnaire. The questionnaire contained questions on the local requirements, distribution and sensitivity to a range of recreational activities. The full questionnaire can be found in Appendix 3. A list of the experts who were consulted and kindly shared their expertise and research findings can be found in the full version of this report. A discussion of each key species or species group, based on the knowledge shared in the questionnaires, is found in the section below.

A selection of key Dartmoor species of local, national and international importance, and representing a broad range of habitats and species groups, was made from two local publications; the State of Dartmoor's Key Wildlife, and the Devon Special Species List. A number of additional species were added based on expert opinion (pers. comm. with Prof Charles R Tyler and Richard Knott (DNPA). It is important to note that these species represent only a case study of the potential effects of recreational activities, and that other Dartmoor species not covered here could be equally affected by recreational activities. Questionnaires and species impact case studies were completed for the following species:

Adder
Blue Ground Beetle
Bog Hoverfly
Cuckoo
Dartford Warbler
Dipper
Dunlin
Fairy Shrimp
Greater Horseshoe Bat
Hen Harrier
High Brown Fritillary (combined into one "butterflies" case study)
Marsh Fritillary (combined into one "butterflies" case study)
Narrow-bordered Bee Hawkmoth (combined into one "butterflies" case study)
Nightjar
Otter
Pearl-bordered Fritillary (combined into one "butterflies" case study)
Peregrine Falcon
Plants (generic overview across lower and higher plants)
Raven
Red Grouse
Ring Ouzel
Salmon
Skylark
Snipe
Southern Damselfly
Whinchat
Wood Warbler

The following species were also included in an initial list of selected species, but species impact case studies were not completed due to being unable to contact and/or receive questionnaire responses from suitable species experts:

Dormouse
Keeled Skimmer
Golden Plover (it is worth noting here Golden Plover is an intermittent winter visitor to Dartmoor, and that winter walkers and dogs are thought to cause substantial disturbance to this species. Some information on disturbance to this species can be found in the literature review above).

Following conversations with species experts, the following species that we identified for our initial listing of species were not followed up on because of their limited relevance for recreational impacts:

Cirl Bunting (small population mostly on private land)
Large Blue Butterfly (no longer seen on Dartmoor)
Willow Tit (mostly on closed and private land)
Woodlark (small population mostly on private land)

Two iconic species which breed on Dartmoor in very low numbers are Lapwing and Curlew. Due to their low numbers, species-specific case studies were not conducted as part of this work. However, there is awareness of the critical plight of these birds on Dartmoor, and their breeding is mapped as part of the Rare Bird nesting areas by DNPA. This mapping is briefly discussed below and maps can be seen in Figure 24.

5.2.4 Impacts on key Dartmoor species

Full case studies for can be found in Appendix 4 (note: sensitive information has been retracted – provided to DNPA in full report version). These case studies include an assessment of recreational impacts, along with details on the ecological requirements and conservation status of the species. Where information was available, maps of local hotspots and/or species distribution are presented. Threats other than those from recreational impacts are also discussed.

Recreational activity types and key species impacted by these activities are summarised in Table 11. This list includes only key species for which analyses were conducted via questionnaires, and is therefore not comprehensive.

Table 11. Activity types and impacted key species

Activity type	Affected key species

Walking/ hiking/ running	• Butterflies & moths
	  ▪ low levels of disturbance to individuals
	  ▪ trampling of key vegetation or food plants under high footfall
	• **Cuckoo** (disturbance to breeding behaviour and fledglings)
	• **Dartford Warbler** (reduced breeding performance)
	• **Dunlin** (potential disturbance but currently low spatial overlap with recreation)
	• **Nightjar** (disturbance leading to nest failure)
	• **Plants** (trampling damage)
	• **Raven** (potential future breeding disturbance)
	• **Ring Ouzel** (disturbance and nest failure)
	• **Whinchat** (breeding disturbance)
	• **Wood Warbler** (disturbance to territory settlement and breeding)

Large events	• **Adder** (disturbance to breeding areas) • **Butterflies & moths** (trampling of key vegetation or foodplants) • **Cuckoo** (prolonged disturbance and displacement of birds from sites) • **Dartford Warbler** (prolonged disturbance) • **Dunlin** (prolonged disturbance) • **Plants** (trampling damage) • **Red Grouse** (prolonged disturbance) • **Ring Ouzel** (prolonged disturbance) • **Skylark** (increased trampling risk due to nests in open vegetation) • **Southern Damselfly** (trampling of key habitat) • **Wood Warbler** (breeding disturbance and trampling risk)
Dog-walking	Effects similar to walking with additional negative effects,, e.g: • **Adder** (disturbance) • **Cuckoo** (disturbance to breeding behaviour and fledglings) • **Ground-nesting birds** (generally more easily disturbed by dogs than by humans only, increased flushing at nests can

Activity type	Affected key species
	lead to increased predation risk) • **Plants** (potential nutrification)
Mountain-biking	• **Nightjar** (disturbance from off-road cycling in conifer plantations) • **Plants** ("trampling" damage) • **Wood Warbler** (potential breeding disturbance)
Horse-riding	• **Plants** (trampling damage)
Increased car traffic	• **Adder** (occasional collision death) • **Butterflies & moths** (occasional collision death) • **Cuckoo** (occasional collision death) • **Greater Horseshoe Bat** (collision death, disturbance to commuting from lights at night) • **Otter** (occasional collision death) • **Plants** (possible indirect effects due to reduced air quality)
Wildlife watching/ naturalists	• **Butterflies & moths** (illegal collection) • **Hen Harrier** (disturbance of roost sites by birdwatchers) • **Ring Ouzel** (disturbance and nest site trampling can lead to displacement and reduced breeding success) • **Wood Warbler** (prolonged breeding disturbance due to information-sharing between photographers)
Fire/arson	• Butterflies & moths (habitat loss) • **Plants** (vegetation loss)
Camping/ barbecues/ picnics	Causes prolonged disturbance and/or displacement, such as: • Most **breeding birds** when activity takes place in/near territory
Kayaking/ swimming/ fishing	• **Dipper** (potential disturbance to territorial behaviour, foraging behaviour and fledglings) • **Plants** (loss of lower plant species from stones at access points, trampling) • **Salmon** (exploitation from illegal fishing, potential disturbance from dams created by visitors)
Caving	• **Greater Horseshoe Bat** (disturbance if roosting or hibernating in caves)
Climbing/ bouldering	• **Peregrine Falcon** (reduced breeding success) • **Raven** (breeding disturbance) • **Ring Ouzel** (potential for future disturbance at breeding sites)

Activity type	Affected key species
Illegal raves	General disturbance to wildlife, e.g. • Nightjar
Letterboxing/ geocaching	• **Plants** (loss of lower plants from stones) • **Ring Ouzel** (prolonged disturbance)
Joy-riding (motorised off-road vehicles)	• **Southern Damselfly** (damage to key habitat)

Based on the questionnaire results, we assigned the key species into three levels of sensitivity to recreation activities, using the following categories:

Green: recreation impact unlikely. Species are either:

- not likely to be affected by any of the listed recreational activities, or
- spatial overlap between recreation and species occurrence is minimal, therefore substantial conflict is unlikely

Orange: recreation impact possible or minor

- Minor or localised recreation impacts could be a concern
- Strong effects unlikely (unless there are major changes in recreation patterns)

Red: recreation impact high or likely

- Adverse impacts have been recorded
- Spatial conflict and recreational impacts deemed likely

The sensitivity category for each species is displayed in Table 12. Sensitivity colours are assigned in the context of the current status of the species on Dartmoor, and the level of recreational use currently seen and realistically expected in the future for Dartmoor. These groupings are therefore specific to Dartmoor, and would not necessarily be applicable to other locations, for example areas with higher recreational pressures or were there are different species distributions and hotspots. For example, although Skylark are sensitive to recreation impacts, strong population-level effects from recreation activities are unlikely due to their widespread presence on Dartmoor, and Skylark are therefore classed as "orange" in terms of sensitivity risk. Another example is the Peregrine Falcon, classed as "green" in our assessment because birds currently breeding on Dartmoor are mostly found on private sites, and are therefore unlikely to be impacted by recreational activities. It is worth emphasising however, that their past status may have included birds breeding on more publicly accessible sites, and that recreational activity may have already resulted in birds deserting those potential breeding sites. If Peregrine Falcon were to start breeding on tors were climbing takes place, sensitivity to recreation impacts would be high. Similar patterns apply to the other species in Table 12. It would therefore be desirable to review the information presented here periodically, especially when species distributions or recreational activities show significant changes.

Table 12. Current sensitivity of key Dartmoor species to recreational activities

Green: recreation impact unlikely	Orange: recreation impact possible or minor	Red: recreation impact high or likely
Blue Ground Beetle	Adder	Cuckoo
Bog Hoverfly	Hen Harrier	Dartford Warbler
Fairy Shrimp	High Brown Fritillary	Dipper
Otter	Marsh Fritillary	Dunlin
Peregrine Falcon	Narrow-Bordered Bee Hawkmoth	Greater Horseshoe Bat
Snipe	Pearl-Bordered Fritillary	Nightjar
	Plants	Raven
	Salmon	Red Grouse
	Skylark	Ring Ouzel
	Southern Damselfly	Whinchat
		Wood Warbler

It is important to emphasise that the species were assigned to the three groups by judging the species' sensitivity based on the above categories and questionnaire information; this is a relatively subjective method. This limitation should therefore be kept in mind. The information, nonetheless, provides a useful overview of the differences between species in their (potential) susceptibility to impacts from recreational activities on Dartmoor.

For the species for which mapping data were available, hotspot maps were produced for the red and orange sensitivity-classed species from Table 12 (maps were provided to DNPA – retracted here due to sensitive information on the location on vulnerable or rare species). Due to limitations in species data or species knowledge, these maps are not comprehensive; for some species it represents all known hotspots (e.g. Wood Warbler), for other species sites of high breeding potential (Salmon) or key foraging areas (Greater Horseshoe Bat). Such mapping efforts therefore do not therefore provide a comprehensive map of all species hotspots on Dartmoor, but rather it provides an informative overview of known hotspot sites for key species, and therefore illustrates sites of conservation importance across the moor.

Further key areas of conservation importance, namely Special Areas of Conservation (SAC), National Nature Reserves (NNR), Sites of Special Scientific Interest (SSSI) and

Rare Bird nesting areas are shown in Figure 24 below. The rare bird nesting area data layer was created by DNPA from rare bird data layers, including Ring Ouzel, Dunlin, Curlew and Lapwing. Dartmoor's Premier Archaeological Landscape Sites data was created as part of creating a Vision for Dartmoor's moorland in 2005. (Permission was granted to map the data layers for the purposes of this report.)

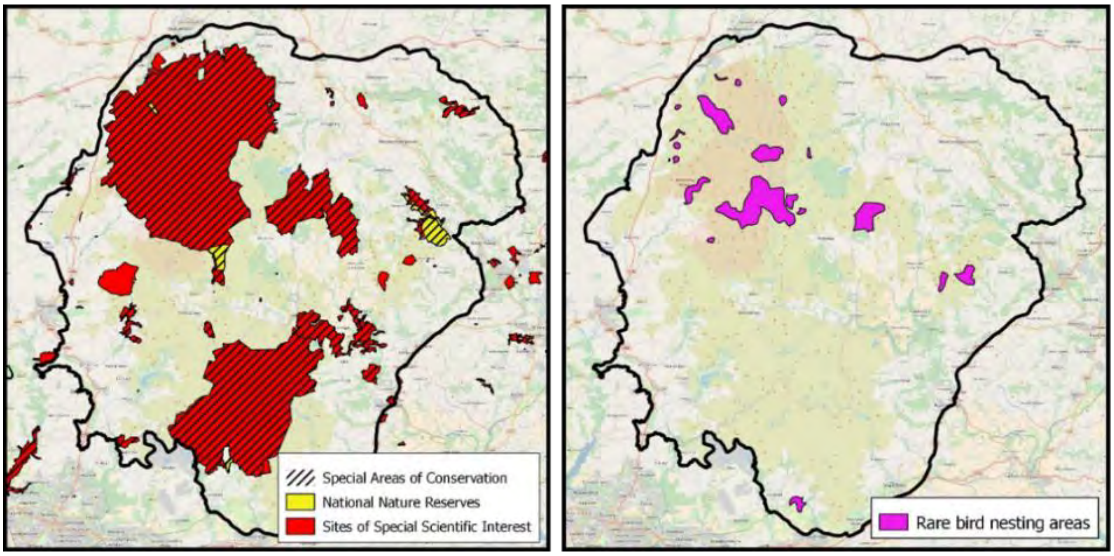


Figure 24. Maps illustrating known sites of conservation importance on Dartmoor.

5.2.5 Impacts on key Dartmoor species – vulnerable locations

Predictions of changes in footfall over the coming decades can be seen in section 3.3.4. This data on predicted changes in footfall can be combined with the information on key species hotspots (Section 5.2.4) to illustrate where species may be under threat from increased recreation. For the species deemed sensitive to recreation, impacts based on expert opinion (see Table 12), the predicted footfall data can be used to establish the likelihood of recreation impacts in future years. It is important to note that this can only be mapped for species where hotspot information was available. For the other case study species, insufficient hotspot information was available. Species such as Dartford Warbler and Whinchat, for which we have no specific hotspot data, but are nonetheless likely to be impacted by increased footfall, are therefore not covered in these mapping efforts. Due to the sensitive nature of several species – only maps for Cuckoo are shown here as an example. Full maps for other sensitive species were provided separately to DNPA.

Figure 25 shows the predicted growth in footfall (in numbers of visitors/hour) between 2019 and 2039, along with the hotspot locations for Cuckoo.

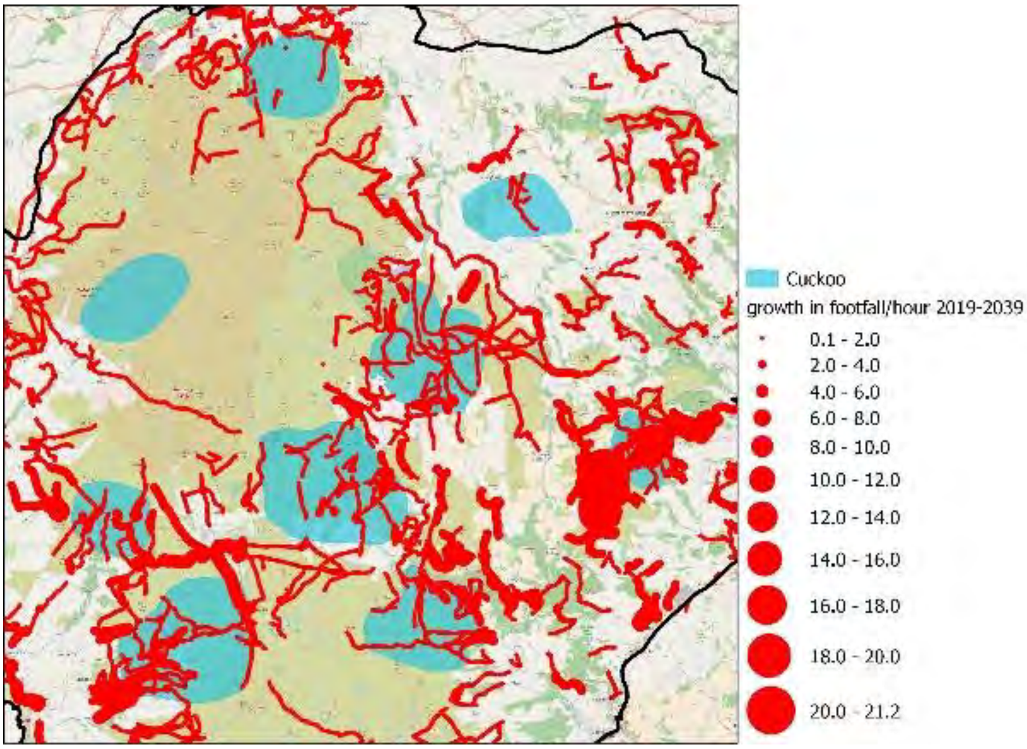


Figure 25. Predicted growth in footfall per hour between 2019 and 2039, superimposed on hotspots for Cuckoo. Figures on other species have been retracted from this report version due to the sensitive nature of the information.

From the mapping efforts for all sensitive species (retracted here due to sensitive location information), it can be seen that species differ in the amount of increased footfall they are expected to experience. The species can be divided into three categories:

- High concern, recreation impacts are likely to increase across most hotspots:
  - Nightjar, Cuckoo and Wood Warbler: footfall will increase at all, or nearly hotspot sites for these species.
- Sites of concern, recreation impacts increasing locally:
  - Dipper, Greater Horseshoe Bat, Red Grouse and Ring Ouzel: increased footfall is expected at part of the hotspot sites for these species.
- Increased impacts from recreation unlikely:
  - Dunlin: very little increased footfall is expected at Dunlin hotspots.

This information indicates that of the species deemed sensitive to recreation impacts, Cuckoo, Nightjar and Wood Warbler are of relatively high concern. Furthermore, increases in footfall are also expected on important sites for Ring Ouzel, Red Grouse, Greater Horseshoe Bat and Dipper (and also for the only current breeding site for Curlew). These species would benefit from further monitoring, and mitigation measures (see section 5.3) should be considered as being beneficial to ensure increased footfall does not negatively impact on their populations. Dunlin is unlikely to experience changes in recreation pressures, and therefore for this species, changes in management practices with regards to recreation impacts are unlikely to be a priority in the near future.

A combined map of key species hotspots and areas of growth in footfall is shown in Figure 26. This map includes all species deemed sensitive to recreation impacts based on expert opinion (see Table 12). It illustrates overall areas where key species and recreation are predicted to come into increased conflict.

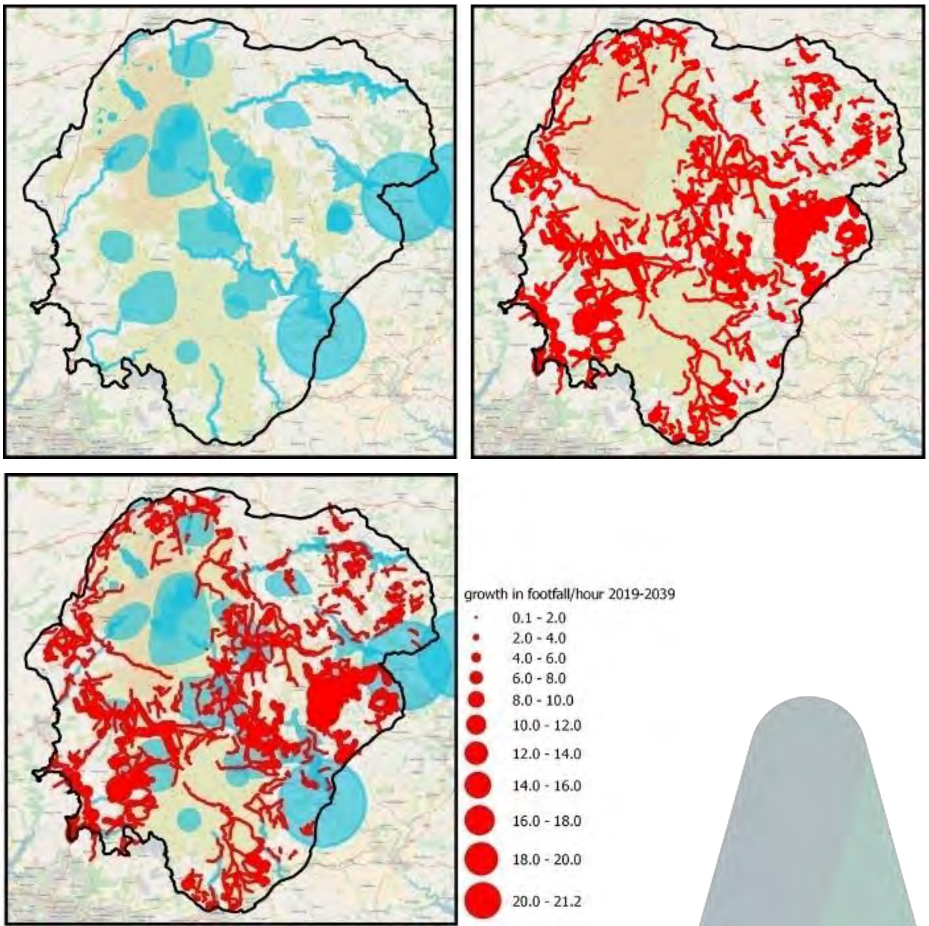


Figure 26. Key species hotspots (for which spatial information was available) (top left), predicted growth in footfall per hour 2019-39 (top right), and combined (bottom panel)

Based on Figure 26, we can highlight 4 vulnerable wildlife locations where particularly strong increases in footfall are expected between now and 2039 (Figure 27):

- Burrator area
- Dart Valley and Venford Reservoir
- Haytor area
- Warren House/Soussons/Fernworthy area

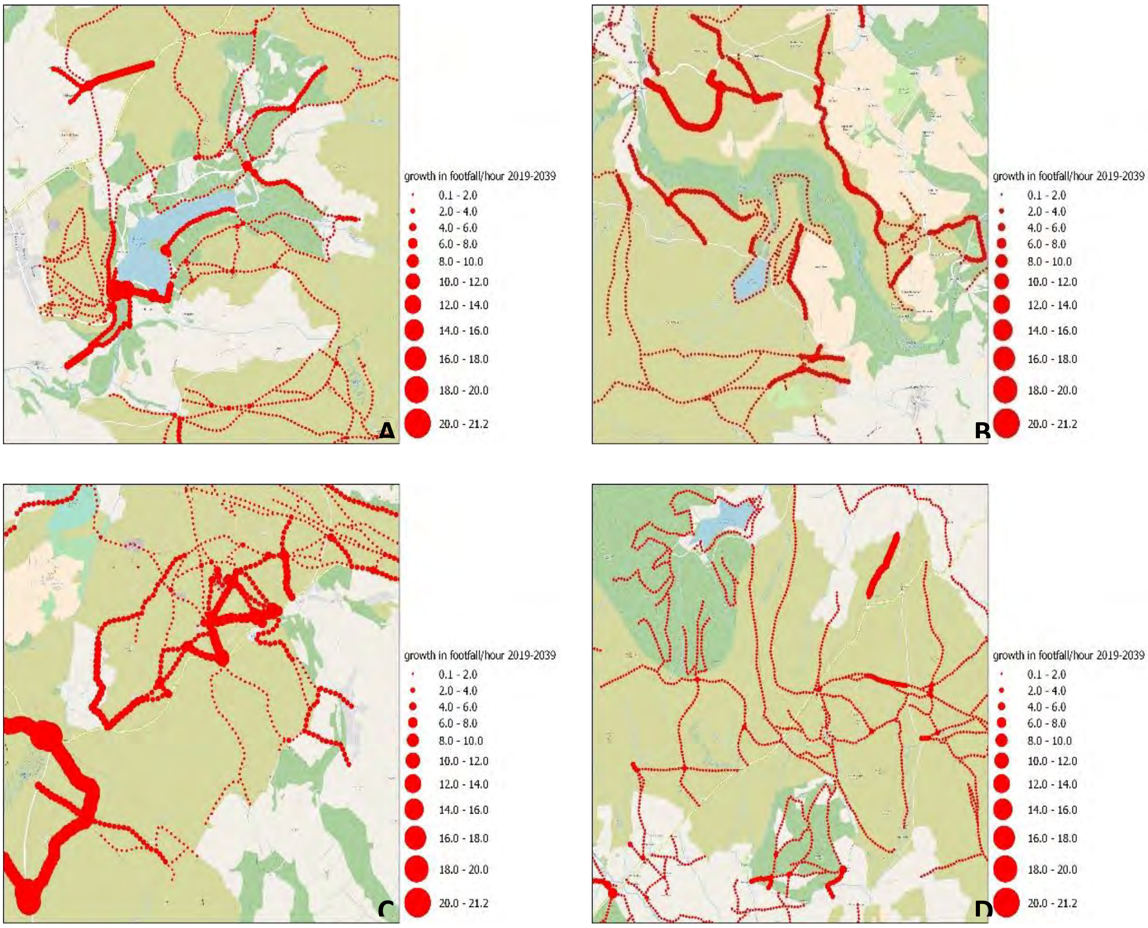


Figure 27. Vulnerable areas where key species hotspots and predicted increases in recreational pressure overlap. A: Burrator area, B: Dart Valley and Venford reservoir, C: Haytor area, D: Warren House/Soussons/Fernworthy area.

It was shown (section 3.1.4 and Figure 6) that visitors from a given LAD tend to focus trips to areas in the National Park that are closest to their location of residence. To understand from where the visitor growth in the four vulnerable areas (Figure 27) will originate, the growth in footfall is mapped separately for each LAD:

- **Burrator area** (Figure 28): The growth in footfall around this area is predicted to originate almost exclusively from the Plymouth, West Devon and the South Hams LADs. The highest increase in footfall is expected from the Plymouth area.
- **Dart Valley and Venford Reservoir** (Figure 29): The largest increase in footfall is predicted to come from the Teignbridge local authority area, with the Exeter, East Devon, Torbay, South Hams and Plymouth LADs also showing substantial growth in footfall across much of the Dart Valley and Venford Reservoir area.
- **Haytor area** (Figure 30): Increases in footfall around Haytor are predicted to originate from all local authority areas. The figure shows that visitors from the Teignbridge area are making the largest contribution to this growth
- **Warren House/Soussons/Fernworthy** (Figure 31): The total predicted hourly growth in footfall in this area appears to consist of visitor growth originating from all local authority areas, which is perhaps unsurprising given the central Dartmoor location of the Warren House/Soussons/Fernworthy area.

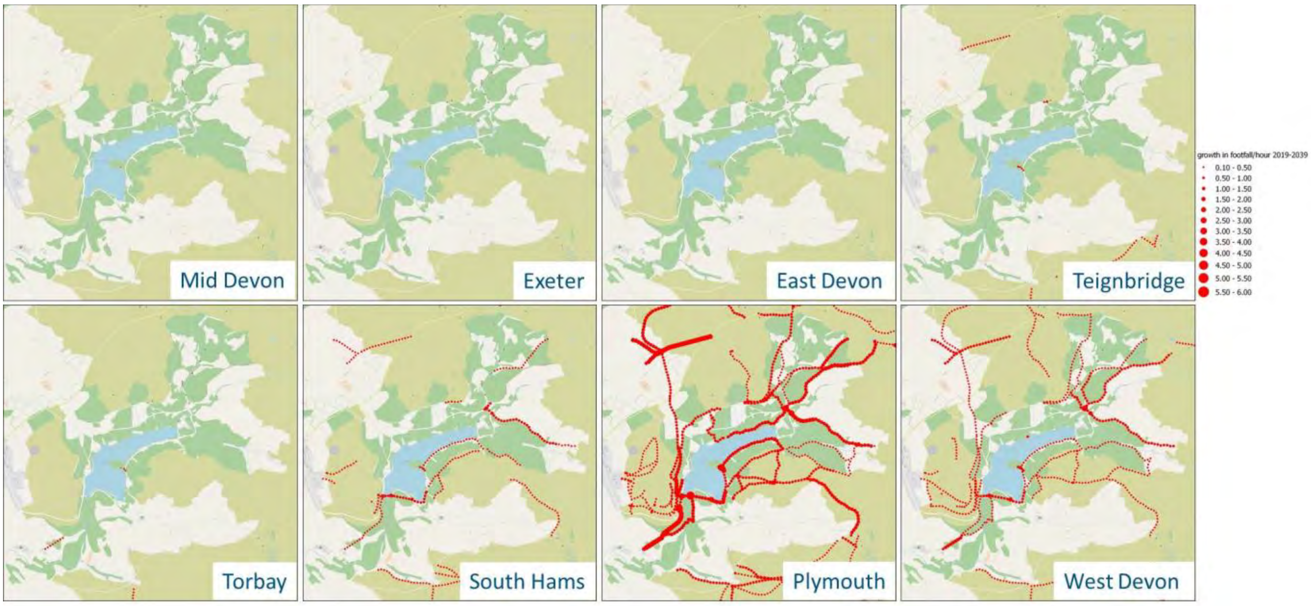


Figure 28. Growth in footfall per hour from 2019 to 2039 for the Burrator area, split by local authority area.

Figure 29. Growth in footfall per hour from 2019 to 2039 for the Dart Valley/Venford reservoir area, split by local authority area.

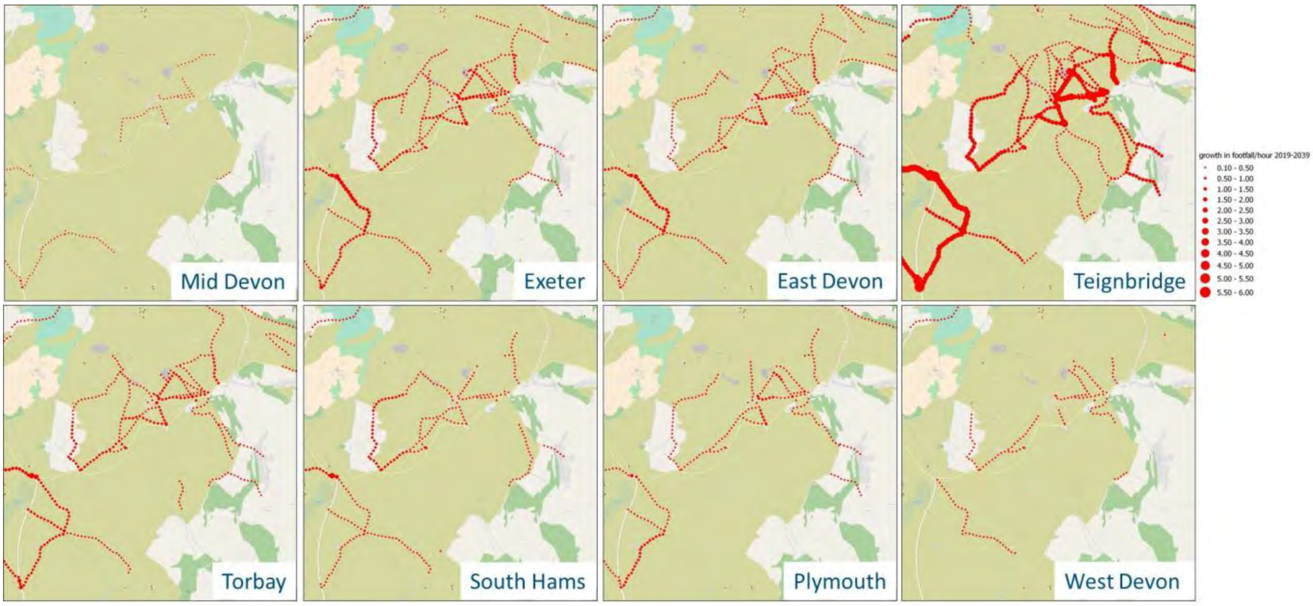


Figure 30. Growth in footfall per hour from 2019 to 2039 for the Haytor area, split by local authority area.

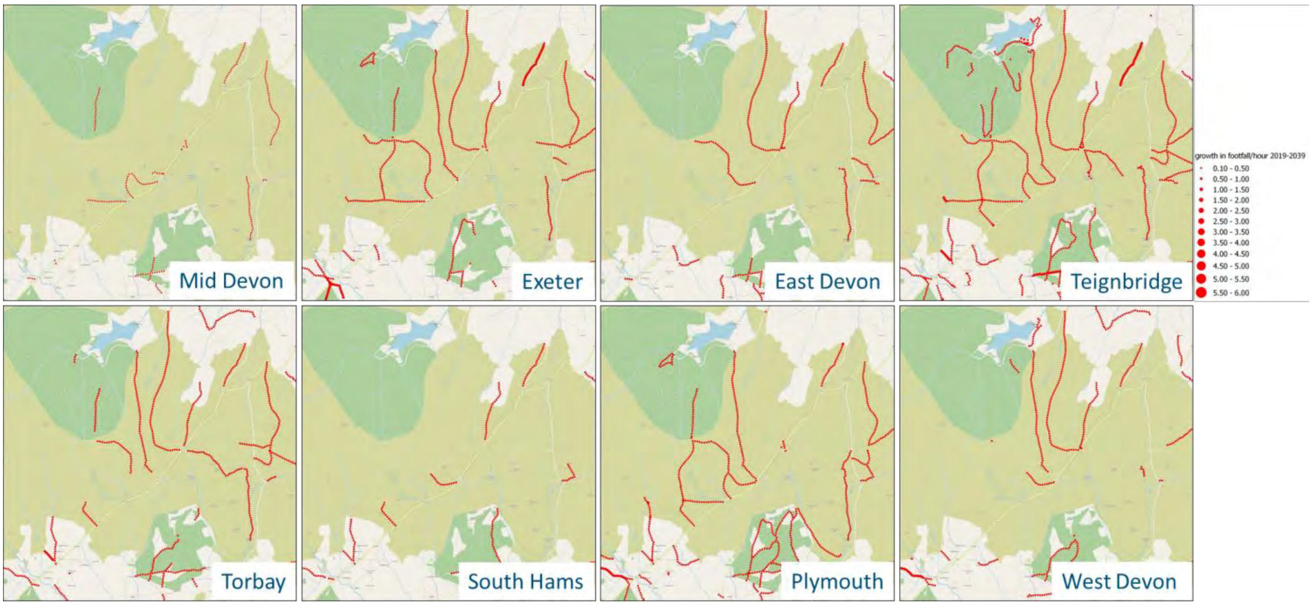


Figure 31. Growth in footfall per hour from 2019 to 2039 for area around Warren House, Fernworthy and Soussons, split by local authority area.

The vulnerable areas described above are examples only; wildlife and increased footfall may come into conflict at numerous other sites, also for species which were not investigated in this study. Furthermore, based on this information, precise effects of increased footfall on these species cannot be predicted. Threshold levels of footfall, above which negative effects occur, are largely unknown, and will differ between species, time of year, and other factors such as vegetation type or site geography. Detailed studies would be needed to derive species-specific recommendations on harmful footfall levels, but the information here can nonetheless be used to inform basic management decisions. For example, mitigation can be prioritised in the indicated vulnerable areas, as larger changes can be expected on those sites compared to other areas of Dartmoor.

Although threshold levels above which negative impacts of recreational activities occur are currently unknown, it is possible to make some abstractions for Dartmoor based on studies from other sits reported in the scientific literature. To illustrate this, we can use data from Murison et al. (2007)[8], who showed that reproductive output of Dartford Warbler in heather territories was reduced (by preventing multiple brooding) when 13 to 16 people passed through a territory each hour. Using this information, it is possible to map Dartmoor sites where the number of visitors is expected to change from less than 13 an hour (currently) to 13 or more per hour (in

[8] Murison et al. (2007) Habitat type determines the effects of disturbance on the breeding productivity of the Dartford Warbler *Sylvia undata*. Ibis. 149. p16-26

2039). These data are presented in Figure 32 (left panel). If Dartford Warbler are found breeding in heathland habitat on any of the sites marked in red (left panel), we could expect a decrease in breeding success at those sites due to disturbance from recreation. It is important to note that many sites have already passed the threshold over 13 visits per hour (see section 3.3.4), so Dartford Warbler breeding performance may already be currently affected by recreational pressures at current high footfall sites.

Dartford Warbler breeding sites are mapped in the Devon Bird Atlas (www.devonbirdatlas.org). Atlas data were not available for this report, but future exploration of this data would be recommended to allow for a more detailed exploration of potential conflict sites where mitigation measures would likely be beneficial for this species.

Figure 32 (middle and right-had panel) serves to illustrate sites with changes in footfall for hypothetical species with lower and higher disturbance threshold levels than Dartford Warbler.

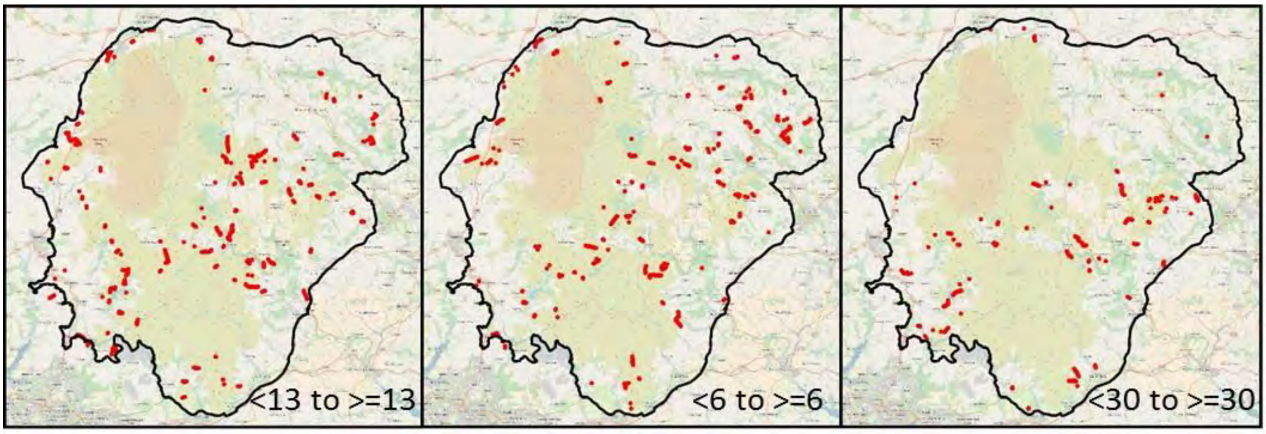


Figure 32. Sites where between 2019 and 2039, footfall per hour is expected to change from less than 13 to 13 or more (left panel), from less than 6 to 6 or more (middle panel) and from less than 30 to 30 or more (right panel).

The middle panel illustrates sites where levels of footfall increase to once every 10 minutes (6 per hour) between 2019 and 2039. The right hand panel illustrates sites where it increases to once every two minutes. This represents locations where thresholds will be crossed for species which are more resilient to disturbance, and for species which are more sensitive to disturbance. These values fall within a range of sensitivity levels which we can realistically expect to see in Dartmoor species, as illustrated by for example Mallord (2007), who showed that +- 8 disturbance events per hour decreased the probability of habitat colonisation in Woodlark. Local research into threshold levels would be valuable for better understanding the implications of increased footfall on sensitive species. Suitable model species for such a study could for example include Wood Warbler and Whinchat, where substantial local research effort and expertise is already available on Dartmoor.

The spatial distribution of further sites of conservation significance (protected areas, rare bird breeding areas and archaeological sites) were shown in Figure 24. To illustrate the expected increase in footfall in these areas, growth in footfall is mapped onto these areas in Figure 33. From this figure, it is apparent that increases in footfall are expected across a range of sites of high importance for wildlife and archaeology. Areas of concern show similarity with those identified from the species hotspot mapping; the Dart Valley, Haytor and Warren House/Soussons areas show a substantial predicted growth in footfall in locations of SSSI sites, archaeological sites and rare bird nesting areas.

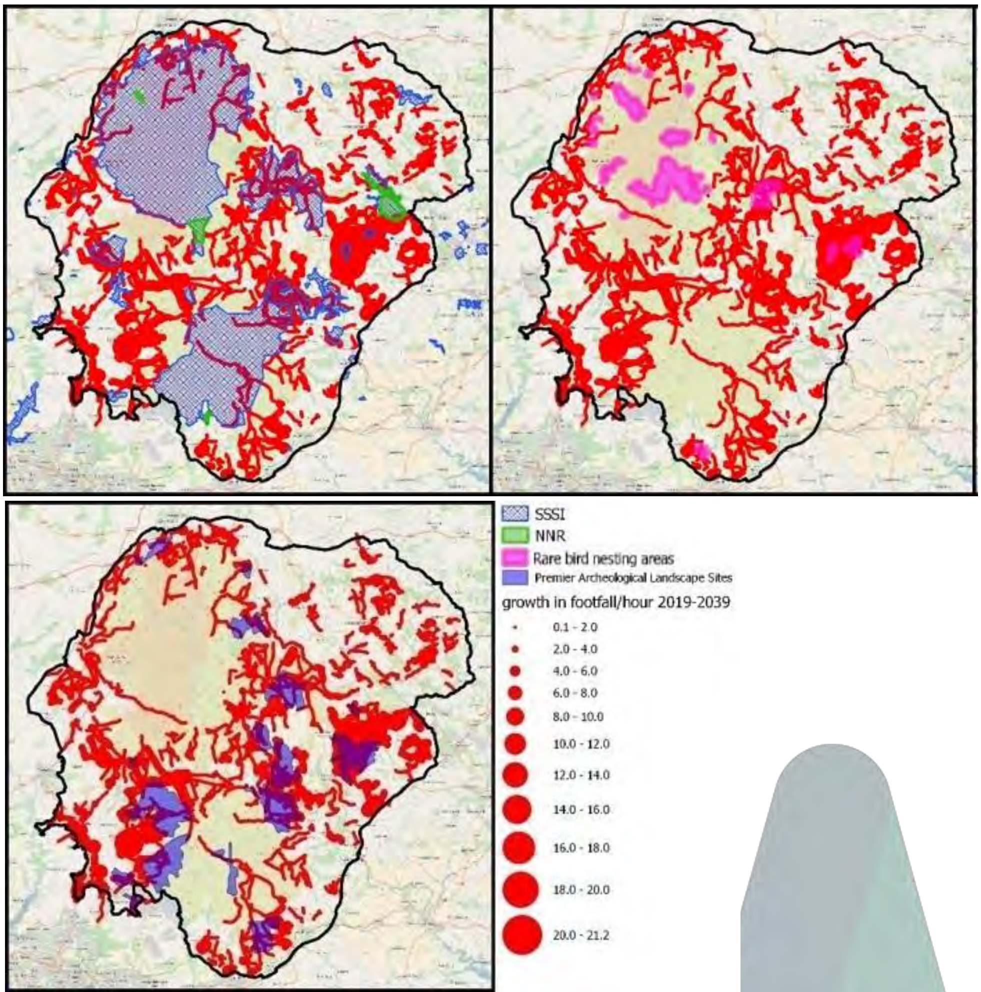


Figure 33. Increased hourly footfall 2019-39, mapped with the locations of SSSIs, NNRs, rare bird nesting areas and Premier Archaeological Landscape sites.

It is perhaps unsurprising that many of the sites of interest in Figure 33 are predicted to show some of the largest increases in visitor pressure, as such sites are popular with visitors due to their special features. To ensure successful protection and continued enjoyment of the National Park's unique assets, it will be key to ensure appropriate protections are put in place in order to prevent damage to the archaeology, flora and fauna. The impacts of increased footfall on archaeological features were not investigated for the purposes of this report, and therefore further investigation into this topic would be beneficial in aiding management decision-making.

5.3 MITIGATION MEASURES

Table 13 below provides an overview of potential measures to mitigate the impacts of recreational pressures. These mitigation measures (presented in no particular order) were suggested by species experts in the key species questionnaires. Additional mitigation measures, as suggested in relevant studies in the scientific literature, can be found in section 5.2.2.

Table 13. Mitigation measures to minimise impacts of recreational activities on key wildlife species.

MITIGATION MEASURE	BENEFITS	LOCATION	TIMING
No large events (e.g. runs/walks) during bird breeding season	Dunlin, Cuckoo, Red Grouse, Wood Warbler, Skylark other breeding bird species. Plants.	Any known or suspected breeding hotspots on the moor. Wood Warbler woodlands. On tors to prevent plant damage.	March-August bird breeding period. Year-round on sensitive tors to prevent plant damage
Strictly enforcing dogs on leads policy during bird breeding season	Adder, Breeding birds (e.g. Cuckoo, Nightjar, Skylark, Whinchat),	Across Dartmoor with particular focus on bird and Adder hotspots	Particularly during bird breeding period (March-August)
Encourage walkers to stick to paths	Prevents trampling of plants and bird nests, reduces bird disturbance	Across Dartmoor, including open moor (e.g. Cuckoo, Whinchat) and woodland/forestry (Nightjar, Wood Warbler). Particularly in sites with hotspots for breeding birds and sensitive plants	Always but particularly during large events and during bird breeding season

MITIGATION MEASURE	BENEFITS	LOCATION	TIMING
Re-design right of way and reserve paths to avoid sensitive areas for Wood Warbler	Wood Warbler	Key Wood Warbler sites (see full report version)	Late April-mid June for temporary closures
Discourage visitors to (remote) tors in spring	Raven, Ring Ouzel, other breeding birds	Key sites (see full report version)	Particularly early to mid-spring for Raven, until summer for other breeding birds
Access restriction E.g. limiting access or re-directing paths. Can also use vegetation management to create habitat barriers (e.g. no burn areas).[3]	Breeding birds (e.g. Dartford Warbler, Nightjar, ground-nesting passerines), Adder, butterflies	Where feasible in bird breeding and Adder hotspots and butterfly sites. For Dartford Warblers, areas with >13 visitors/hour (see species factsheet)	Could be a year-round infrastructure consideration, or seasonal access restriction during sensitive months
Restrict access indirectly by discouraging visitor increases through not adding any additional car parking facilities	Breeding birds, butterflies	Any butterfly and bird breeding hotspots	Year-round infrastructure consideration
Continue existing "Rare Bird Nesting Area" mitigation	Ring Ouzel, waders (and other birds in those areas)	All Ring Ouzel and wader breeding sites	All year, reviewed annually
Restrict and reduce night-time lighting, avoid future increase in lighting	Greater Horseshoe Bats (and other nocturnal species)	Maintain year-round dark corridors around all bat priority areas, reduce lighting around key sites (see full report) from May-September	Year-round
Outreach on reduction of disturbance. Explain when birds are disturbed (e.g. alarm calls) and how to reduce disturbance, rather than only highlighting presence of birds.	Breeding birds (including Ring Ouzel, Dartford Warbler and other ground-nesting passerines and waders)	Park rangers and volunteer wardens when coming across public on key wildlife sites (see full report). Potentially online and in visitor centres.	Bird breeding season
Continue to keep information on Hen	Prevent disturbance to Hen Harrier roosts	All sites	Permanently

MITIGATION MEASURE	BENEFITS	LOCATION	TIMING
Harrier roosting sites out of public domain			
Ensure adequate ecological impact assessments are completed. For Otter, potential site use for breeding should be assessed.	Otter, and other protected species more broadly	All sites	Before planning permission is sought
Vegetation management to maximise available suitable breeding habitat	Whinchat	At known Whinchat breeding sites, allow Bracken and heather in areas with sloping ground, gullies and ditches	Year-round
Allowing existing woodland to creep up slopes	Increase breeding habitat for e.g. Wood Warbler away from recreational disturbance	For example Dendles Wood	Year-round
Limit letterboxing and geocaching	Plants	Tors	Year-round
Restrict or ban barbeques	Plants (and birds by preventing prolonged disturbance at one site)	Open moor	Year-round
Continued prevention of illegal raves	Nightjar and other wildlife	Nightjar hotspots (and other wildlife hotspots)	Particularly during bird breeding season
Install roadside boulders to prevent damage to spring feeding Southern Damselfly runnel	Southern Damselfly	Known sites (see full report)	Permanent installation
Prevent off-road cycling off bridleways	Plants, birds	All habitats	Year-round
Campaign for cleaner cars, provide better public transport	Air quality (to support plants)	Across moor	Year-round
Generate improved mapping of Adder	Adder	Across Dartmoor, implement education	March - August

MITIGATION MEASURE	BENEFITS	LOCATION	TIMING
hotspots and educate public to avoid Adder sites		for Adder hotspots	
Research into how human and dog presence affects bird settlement. Local Wood Warbler/RSPB project has study system and expertise in place to undertake this, funding needed to implement study	Wood Warbler as focal species, other birds from wider implications of findings	Key breeding sites (see full report)	
Encourage monitoring of Dipper territory sites and hotspots to ensure birds are successfully breeding	Dipper	Particularly sites with high kayaking activity	Dipper breeding season
Install nestboxes in habitats suitable to Dipper	Dipper	Sites where no natural nesting opportunities currently exist	Before Dipper breeding commences

Several existing mitigation measures which are currently used by DNPA were listed by species experts as desirable. These include the existing policy around discouraging access to rare bird nesting area, prevention of illegal raves, and the policy of keeping details of nesting and/or roosting locations of rare birds (such as Hen Harrier) out of the public domain. The regulation of large events was also identified as an important policy; several bird species experts expressed serious concerns over the possible impacts on breeding birds resulting from the prolonged disturbance arising from such events. While a paucity of scientific data means it is currently difficult to evidence the causal link from disturbance to population outcomes, there are sufficient grounds for concern to support the continued regulation and limitation of large events, particularly at bird breeding hotspots during the March to April breeding period. It is important to note that this should not only cover events on the open moor; consideration should also be given to woodland species where experts also expressed concerns regarding disturbance from events such as busy woodland visit days.

Our literature review revealed several past studies that have highlighted the disturbance of birds by dogs. Both the consulted Dartmoor species experts and the reviewed scientific literature raised “dogs on leads” policies as an important mitigation measure. In addition to preventing disturbance to breeding birds and livestock, it might also help minimise dog-Adder conflict and associated negative perception of Adders. A “dogs on leads” policy is already in existence and can benefit a wide range of ground-nesting bird species. Again the evidence, while still limited, supports the spatially and temporally targeted continuation of this policy, reinforced by outreach programs and, where feasible, enforcement.

Our analysis also revealed a number of targeted, smaller scale interventions which would be relatively straightforward to implement and are likely to benefit a number of key species. In suitable Dipper habitats where no natural nesting areas currently exist, the installation of Dipper nestboxes could add valuable breeding opportunities. Likewise, an outreach initiative to help the general public understand how to recognise and reduce disturbance could benefit wildlife, and would educate and engage the public in taking an active role in wildlife protection. Such an initiative might include online materials and flyers on recognising the behaviour of disturbed birds (e.g. alarm calling), and recommendations on how to reduce disturbance (e.g. targeting picnickers, geocachers, campers and climbers). Rangers and wardens could also contribute to outreach initiatives by actively educating the public on these issues at key sites (e.g. Ring Ouzel hotspots). A final targeted mitigation measure is the use of temporary path closures and path network re-designs to avoid sensitive areas for Wood Warbler, particularly in East Dartmoor NNR, Dunsford Woods and Fingle Bridge. Such access restrictions should also be considered in other areas where recreation and wildlife come into conflict; for example, our literature overview highlighted access restrictions as a recommended mitigation measure for Nightjar.

In addition to the targeted mitigation measures outlined above, wider habitat management is key in providing sufficient suitable habitats for wildlife. Habitat enhancement or habitat creation can be used in strategic locations away from recreation hotspots in order to maximise the availability of habitat for key species. For example, Whinchat are known to show affinity for sloping ground, gullies and ditches with Bracken and heather cover. Therefore, encouraging such vegetation in areas with those geographical features will increase breeding site options for this species. On woodland edges, some allowance for vegetation to creep up the slopes can increase the availability of Wood Warbler breeding sites away from highly-used footpaths in the woodland valleys (for example in Dendles Wood). More generally, encouraging a rich diversity of vegetation types across the moor will ensure the availability of suitable habitat for a wide range of species. For example, avoiding burning in selected patches can create a mosaic of higher shrubbery to support a range of invertebrates and birds. Where used in targeted locations, this could also help reduce habitat penetrability for dogs and humans, and can therefore be used strategically to discourage recreational activity and prevent footpath creation or footpath widening in areas of concern.

A further broad mitigation measure is the active creation of "wildlife refuge areas" where recreation is discouraged. Temporary path closures can be used to prevent visitors entering sites where vulnerable species are found. However, full access restrictions are often not a management option, and a range of alternative techniques can be used to discourage visitation to particular areas. As mentioned above, using patches of higher vegetation around key wildlife sites can reduce visitor numbers by reducing the accessibility of sites. Reduction (or prevention of expansion) of parking availability, and the provision of alternative access points can have similar effects. Signposting along access points and footpaths can be used to encourage visitors to take specific routes, thereby taking a land-sparing approach to recreational activities. The active creation of such "wildlife refuge areas" is not recommended to be necessary on the high open moors, which are natural refuges due to their inaccessibility and subsequent low levels of footfall. Areas which may be particularly suitable for the interventions outlined above are sites which are important for wildlife whilst not showing high predicted levels of increased footfall. Examples include the Tavy Teign and Bovey Valleys. On key conflict sites such as Warren House and Venford/Dart Valley, vegetation management and signposting could be used to encourage visitors towards certain areas whilst maintaining local wildlife refuges in these areas. A big honeypot site such as Haytor, which is predicted to experience large increases in visitor numbers over coming decades, may be a site of choice for the encouragement of recreation through promotion and the provision of additional access and facilities to draw visitors to this area, thereby sparing other sites. This can of course be combined with further access management (e.g. higher vegetation, footpath closures) at this site in order to discourage visitors from straying into nearby areas of conservation importance.

6 SUMMARY AND CONCLUSIONS

The findings presented in this report provide a detailed assessment of the likely impacts on Dartmoor of future population growth in the region. The first major contribution of this work has been to construct spatialized predictions of population change in the Dartmoor hinterland from 2014 to 2039. Those predictions draw on Office of National Statistics population projections augmented by details of property developments that are expected in the region that are described in the Local Plans of the eight Local Authority Districts (LADs) that surround the National Park.

To understand how these new residents of the region might use Dartmoor, the spatialised population projections have been coupled with the Outdoor Recreation Valuation (ORVal) tool. ORVal is a sophisticated recreation demand model developed by the LEEP institute at the University of Exeter using data from the Monitor of Engagement with the Natural Environment survey. With the help of local experts, a bespoke calibration of the ORVal tool has been developed for this project that allowed for the prediction of expected visitation to the array of recreation sites across Dartmoor National Park. That model indicates that Dartmoor is currently the backdrop for over 7 million day trips per year from residents of the eight neighbouring LADs. Moreover, increased populations in those LADs will result in a predicted additional 870,000 annual visits to Dartmoor per year, a rise of some 12%.

A further novel modelling exercise was undertaken that sought to extend the ORVal estimates of visitation into estimates of intensity of footfall through the National Park. That model used evidence from various sources to approximate how far visitors might travel through the paths network during their visits. The resulting estimates of the spatial dispersion of visitors and the intensity of footfall across the National Park allows us to address a number of questions regarding the impact of recreation on Dartmoor.

While the modelling framework developed for this project provides a sophisticated toolkit with which to address the primary objectives of the research, one weakness is that the models lack solid primary evidence that could be used to verify their predictions. One area of future research that DNPA might consider pursuing is the structured quantification of recreation demand and activities across the National Park.

The report addresses both the benefits and the costs of increased recreation activity on Dartmoor. With regards to benefits, a key measure is that of economic welfare, a monetary estimate of the enjoyment that visitors realise from their visits. Economic welfare can be directly estimated using the calibrated ORVAl tool. Indeed the model estimates suggest that Dartmoor is currently the source of £25.6 million of welfare benefits to the residents of the 8 neighbouring LADs each year and that as a result of population increases that number will likely rise by £2.5 million by 2039. Those benefits are not evenly distributed across the neighbouring LADs. Rather the largest welfare values are realised in those LADs with significant populations in and around Dartmoor including Teignbridge, West Devon and Plymouth.

The report also attempts to quantify the health benefits of the physical activity enabled by recreational access to the National Park. The footfall model provides prediction as to how far visitors to Dartmoor might be expected to walk in the National Park. Translating walking distances into energy expenditure provides an estimate the level of fat burned by visitors. Those estimates suggest that residents of the eight local LADs burn around 100,000 kg of fat each year as a result of their physical activities on Dartmoor.

Of course, these recreational benefits do not come without cost. As per the projects objectives, here we have focused on environmental costs particularly those that arise from the physical erosion of and the disturbance of Dartmoor’s wildlife.

Transferring findings from a detailed study of the English Lake District, the report uses the footfall intensity estimates along with measures of path slope and altitude to predict rates of footpath erosion. Our analyses suggest that increasing recreational pressure on Dartmoor may result in 10,854 m^2 of bare ground being exposed along the path network and increased gullying along 42km of path.

Again the analyses suffer from a paucity of data on path erosion on Dartmoor. Another area where improved information would be valuable for management purposes would be in the form of a structured analysis of recreation pressure and path erosion, a study that might employ developing technologies such as drones or remotely-sensed Lidar data sets.

In the context of impacts on wildlife disturbance, this report gives an overview of scientific studies which have recorded a wide range of impacts of recreational activities, including changes to animal behaviour, distribution and reproductive success. Questionnaires conducted with local species experts indicate cause for concern on the impacts of recreation on a wide range of key Dartmoor plant and animal species. Examples of species of particular concern include Cuckoo, Nightjar, Ring Ouzel and Wood Warbler. Activity types which have negative effects differ between species, but walking, dog-walking and large events are key concerns across many of the investigated key species.

Once again, the detailed science regarding threshold levels of recreation at which species incur disturbance that might impact on reproductive success is lacking. Indeed, more species-specific research in a Dartmoor context is needed to understand the footfall levels at which negative effects occur.

All the same, four sites of conservation importance have been identified where large increases in footfall are predicted over the coming years. These sites are the areas around i) Burrator, ii) the Dart Valley and Venford Reservoir, iii) Haytor, iv) Warren House, Soussons and Fernworthy. At these sites, an increased conflict between recreation and wildlife can be expected, and mitigation measures could therefore be prioritised there. Mitigation measures derived from both expert opinion and past research are outlined in the report. Measures suggested to be beneficial to a broad range of species include (temporary) access restrictions, management of large events, enforcement of the dogs on lead policy and public education.

In addition to this report, an accompanying assessment on planning and legal systems was conducted in order to identify potential alternative income streams to fund mitigation measures. Further details can be found in the assessment report by Green Balance and Kristina Kenworthy.[9]

[9] Planning and legal advice – informing assessment of recreational impacts on Dartmoor National Park. Green Balance and Kristina Kenworthy. March 2018.

REFERENCES

Botsch, Y., Tablado, Z., Jenni, L. (2017). Experimental evidence of human recreational disturbance effects on bird-territory establishment. *Proceedings of the Royal Society B.* 284: 20170846.

Brambilla, M., Rubolini, D., Guidali, F. (2004). Rock climbing and Raven *Corvus corax* occurrence depress breeding success of cliff-nesting Peregrines *Falco peregrinus*. *Ardeola*. 51(2), pp. 425-430.

Bravata DM, Smith-Spangler C, Sundaram V, et al. Using Pedometers to Increase Physical Activity and Improve Health: A Systematic Review JAMA 2007; 298: pp. 2296-2304

Breeding Bird Survey of Dartmoor Training Area (2006).

Buckley, R. (2013). Next steps in recreation ecology. *Frontiers in Ecology and the Environment.* 11(8), p. 399

Coleman, R., (1981). Footpath erosion in the English Lake District. *Applied Geography*, 1(2), pp. 121-131.

Davies, N, (2016). *Investigating route-choice by recreational walkers in the English Lake District*, A thesis submitted in partial fulfilment for the requirements for the degree of Doctor of Philosophy, at the University of Central Lancashire.

Day, B. H., and G. Smith (2016). Outdoor Recreation Valuation (ORVal) Data Set Construction. *Report to the Department of Food and Rural Affairs*.

Day, B. H., and G. Smith (2018). The Orval Recreation Demand Model. *Report to the Department of Food and Rural Affairs*.

DNPA (2018). Naturally Healthy Project. Summary Report April 2018.

DCC, 2017. Plymouth Housing Market Area Population & Housing Projections 2014 to 2034. Devon County Council Local Modelling Report. Available online: https://www.plymouth.gov.uk/sites/default/files/PlymouthHousingMarketAreaPopulationHousingProjections20142034.pdf

DCLG, 2016. *2014-based household projections: detailed data for modelling and analytical purposes*. Housing and Planning Analysis Division, Department for Communities and Local Government. Available online: https://www.gov.uk/government/statistical-data-sets/2014-based-household-projections-detailed-data-for-modelling-and-analytical-purposes

East Devon, 2013. East Devon Local Plan 2013-2031. Available online: http://eastdevon.gov.uk/planning/planning-policy/local-plan-2013-2031/

Exeter City Council (2012). Exeter Core Strategy 2012-2026. Available online: https://exeter.gov.uk/media/1636/adopted-core-strategy.pdf

Finney, S.K., Pearce-Higgins, J.W., Yalden, D.W. (2005). The effect of recreational disturbance on an upland breeding bird, the golden plover *Pluvialis apricaria. Biological Conservation*. 121, pp. 53-63

Gill, J.A. (2007). Approaches to measuring the effects of human disturbance on birds. *Ibis*. 149, pp. 9-14.

Jayakody, S., Sibbald, A.M., Mayes, R.W., Hooper, R.J., Gordon, I.J., Lambin, X. (2011). *European Journal of Wildlife Research*. 57, pp. 939-948.

JLP, 2017. *Plymouth and South West Devon Joint Local Plan 2014-2034.* Produced by West Devon Borough Council, South Hams District Council and Plymouth City Council. Available online: https://www.plymouth.gov.uk/planningandbuildingcontrol/plymouthandsouthwestdevonjointlocalplan

Korkanç, S. Y., (2014). Impacts of recreational human trampling on selected soil and vegetation properties of Aladag Natural Park, Turkey. *CATENA*,113, pp. 219-225,

Langston, R.H.W., Liley, D., Murison, G., Woodfield, E., Clarke, R.T. (2007). What effects do walkers and dogs have on the distribution and productivity of breeding European Nightjar *Caprimulgus europaeus*? *Ibis.* 149, pp. 27-36.

LeCheminant, J.D., Heden, T., Smith, J. et al. (2009). "Comparison of energy expenditure, economy, and pedometer counts between normal weight and overweight or obese women during a walking and jogging activity", Eur J Appl Physiol, 106, pp. 675-682. https://doi.org/10.1007/s00421-009-1059-9

Liley, D., Clarke, R.T. (2003). The impact of urban development and human disturbance on the numbers of nightjar *Caprimulgus europaeus* on heathlands in Dorset, England. *Biological Conservation*. 114, pp. 219-230

Mallord, J.W., Dolman, P.M., Brown, A.F., Sutherland, W.J. (2007). Linking recreational disturbance to population size in a ground-nesting passerine. *Journal of Applied Ecology*. 44, pp. 185-195.

Marion, J. (2016a).A review and synthesis of recreation ecology research research findings on visitor impacts to wilderness and protected natural areas. *Journal of Forestry*. 114(3), pp. 352-362

Marion, J. (2016b).A review and synthesis of recreation ecology research supporting carrying capacity and visitor use management decisionmaking. *Journal of Forestry.* 114(3), pp. 339-351

Mid Devon District Council, 2006. Core Strategy 2006-2016. (pages 29-30, 38-49) Available online: https://www.middevon.gov.uk/media/103617/core_strategy_adopted.pdf

Monz, C. A., Pickering, C.M., Hadwen, W.L. (2013). Recent advances in recreation ecology and the implications of different relationships between recreation use and ecological impacts. *Frontiers in Ecology and the Environment*. 11(8), pp. 441-446.

Murison et al. (2007) Habitat type determines the effects of disturbance on the breeding productivity of the Dartford Warbler *Sylvia undata. Ibis.* 149. pp. 16-26

ONS (2011) Output Area to Lower Layer Super Output Area to Middle Layer Super Output Area to Local Authority District (December 2011) Lookup in England and Wales. Office for National Statistics. DATASET. Available online: http://geoportal.statistics.gov.uk/datasets?q=OA_LSOA_MSOA_2011_LU&sort=name

ONS (2014) *SNPP Z1: 2014-based Subnational Population Projections.* Local Authorities in England, mid-2014 to mid-2039. DATASET and REPORT. Available online: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/subnationalpopulationprojectionsforengland/2014basedprojections

Pearce-Higgins, J.W., Finney, S.K., Yalden, D.W., Langston, R.H.W. (2007). Testing the effects of recreational disturbance on two upland breeding waders. *Ibis*. 149, pp. 45-50

Pescott, O.L., Stewart, G.B. (2014). Assessing the impact of human trampling on vegetation: a systematic review and meta-analysis of experimental evidence. *PeerJ.* 2: e360.

Rodway-Dyer, S., Ellis, N. (2018). Combining remote sensing and on-site monitoring methods to investigate footpath erosion within a popular recreational heathland environment. *Journal of Environmental Management.* 251, pp. 68-78.

Roovers, P. , K. Verheyen, M. Hermy, H. Gulinck, and Bakker, J.P. (2004). Experimental trampling and vegetation recovery in some forest and heathland communities, Applied Vegetation Science, 7 (1), pp. 111-118.

Rouifed, S., Piola, F., Spiegelberger, T. (2014). Invasion by *Fallopia* spp. in a French upland region is related to anthropogenic disturbances. *Basic and Applied Ecology*. 15, pp. 435-443.

SHMNA, 2017. *Strategic Housing Market Assessment Part 2 – Objectively Assessed Need for Affordable Housing*. Report compiled by HDH Planning and Development Ltd for Plymouth, South Hams and West Devon Councils. Available online: https://www.plymouth.gov.uk/sites/default/files/StrategicHousingMarketNeedsAssessmentPart2.pdf

Showler, D.A., Stewart, G.B., Sutherland, W.J., Pullin, A.S. (2010). What is the impact of public access on the breeding success of ground-nesting and cliff-nesting birds? CEE review 05-010 (SR16).

Sibbald, A.M., Hooper, R.J., McLeod, J.E., Gordon, I.J. (2011). Responses of red deer (*Cervus elaphus*) to regular disturbance by hill walkers. *European Journal of Wildlife Research*. 57, pp. 817-825.

Steven, R., Pickering, C., Castley, J.G. (2011) A review of the impacts of nature based recreation on birds. *Journal of Environmental Management*. 92, pp. 2287-2294.

Teignbridge District Council, 2014. Teignbridge Local Plan 2033. Available online: https://www.teignbridge.gov.uk/planning/local-plans-and-policy/teignbridge-local-plan-2033/

Torbay Council, 2012. New Local Plan 2012-2030. Available online: http://www.torbay.gov.uk/council/policies/planning-policies/local-plan/new-local-plan/

Vangansbeke, P., Blondeel, H., Landuyt, D., De Frenne, P., Gorissen, L., Verheyen, K. (2017). Spatially combining wood production and recreation with biodiversity conservation. *Biodiversity Conservation*. 26, pp. 3213-3239.

Votruba, S.B., Atkinson, R.L., Hirvonen, M.D., Schoeller, D.A. (2002). Prior exercise increases subsequent utilization of dietary fat. *Medicine & Science in Sports & Exercise*. 34(11), pp. 1757-1765.

Whinam, J. ,Chilcott, N.M. (2003). Impacts after four years of experimental trampling on alpine/sub-alpine environments in western Tasmania. *Journal of Environmental Management*. 67(4), pp.339-351.

Yalden, D.W. (1992). The influence of recreational disturbance on common sandpipers *Actitis hypoleucus* breeding by an upland reservoir, in England. *Biological Conservation*. 61, pp. 41-49.

Yang, Y., and Diez-Roux, A. V. (2012). Walking distance by trip purpose and population subgroups. *American Journal of Preventive Medicine*. 43(1), pp. 11–19.

APPENDICES

Appendix 1. Population Projections

Every two years, the Office for National Statistics (ONS), release national population projections by age and sex. The current release[10] is based on the estimated population on 30 June 2014 and uses demographic assumptions about fertility, mortality and migration to project 25 years into the future (see ONS, 2014). Annual population figures for mid-2014 to mid-2039 for persons, males and females, are released by single year of age at a local government area level in England. *ONS projections use past trends but do not take into account future government policies.* Projections become increasingly uncertain the further they are carried forward (ONS, 2014).

The Department for Communities and Local Government (DCLG) release future projections of household structure and headship rates (at local government area level from 2014 to 2039) (DCLG, 2016). ONS now maintain most of the statistics on households (HH) in England (https://www.gov.uk/government/statistical-data-sets/live-tables-on-household-projections). These include, at a local government area level, total HH, number of dependent children in HH and average HH size. Temporal resolution for these statistics is variable (annual, five-year time step and base to 2039 only).

Other spatially-explicit population data are either both spatially and thematically coarse (e.g. Eurostat), or do not provide projections (e.g. GHSL)[11].

All regions of England are expected to see an increase in their population size over the 25-year period (ONS, 2014) and the population is also ageing (Figure A1).

[10] The next release is due 26 October 2017, but likely not at the subnational level.

[11] Global Human Settlement Layer, GHSL, (source: European Commission) – 250 m resolution for target years 1975, 1990, 2000 and 2015. Derived from 1 km resolution Gridded Population of the World (GPW4).

Eurostat, the statistical office of the European Union, provide population projections at a national level using 2015 as the baseline and projecting to 2081. Demographic age groups are coarse (e.g. children, working age, elderly and oldest old persons).

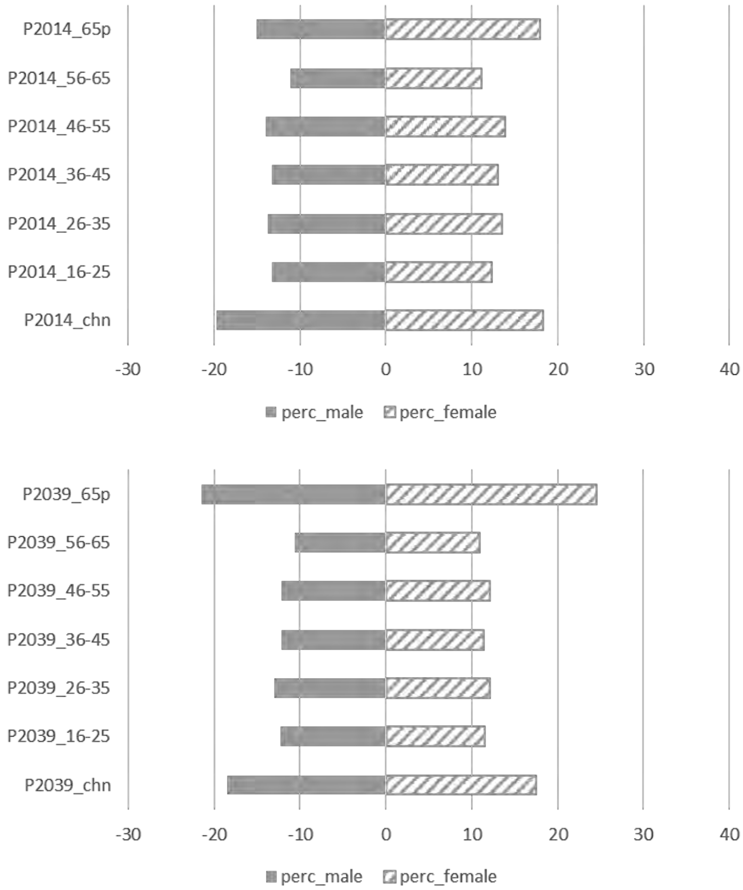


Figure A1. Population structure across England for 2014 baseline (top panel) and 2039 (bottom panel). (Source: ONS 2014, SNPP Z1

Appendix 2. Population changes in Dartmoor's hinterland

Tables B1, B2 and Figure B1 show population increases, and changes to population structure, in the hinterland (see also Table 1 and Figure 2 of the main document). Figure B2 and Table B3 show changes to household (HH) numbers and size.

Table B1. Population change mid-2014 to mid-2039 for local government areas in Dartmoor's hinterland. (Source: ONS 2014, SNPP Z1, rounded nearest thousand)

Area Name	Area Code	Area (km^2)	Persons 2014	Persons 2019	Persons 2024	Persons 2029	Persons 2034	Persons 2039	Overall change (%)
East Devon	E07000040	814	262,000	268,000	272,000	278,000	283,000	287,000	17.9
Exeter	E07000041	47	133,000	136,000	139,000	142,000	146,000	148,000	17
Teignbridge	E07000045	674	136,000	141,000	147,000	152,000	157,000	161,000	16.7
West Devon	E07000047	1161	124,000	130,000	133,000	138,000	142,000	145,000	15.9
Mid Devon	E07000042	913	79,000	81,000	84,000	86,000	88,000	89,000	12.7
Torbay	E06000027	63	84,000	85,000	87,000	89,000	91,000	92,000	11.7
Plymouth	E06000026	80	127,000	132,000	137,000	141,000	145,000	149,000	9.7
South Hams	E07000044	886	54,000	56,000	58,000	60,000	62,000	63,000	9.1

Table B2. Sub-national population projections for Dartmoor's hinterland, male and female for ORVal age structure groupings (base mid-2014 and mid-2039 shown; annual data available). Source: ONS, SNPP Z1.

Area_code	M2014_chn	M2014_16-25	M2014_26-35	M2014_36-45	M2014_46-55	M2014_56-65	M2014_65p	M2014_all	M2039_chn	M2039_16-25	M2039_26-35	M2039_36-45	M2039_46-55	M2039_56-65	M2039_65p	M2039_all
E06000026	23407	23295	17824	15377	16918	13907	19230	129958	25131.918	26281.066	19928.695	16144.998	15105.52	12991.094	29361.644	144944.932
E06000027	11243	7242	6449	7093	9306	8755	14244	64332	12074.851	7327.706	7282.358	6833.506	7987.499	8364.504	23167.855	73038.279
E07000040	11014	6879	5772	7006	9027	9054	17102	65854	12209.017	7468.638	6610.945	7554.873	8936.548	9213.93	27270.048	79264.002
E07000041	10049	13521	9565	7495	7272	5622	7754	61278	11261.369	14928.299	12119.503	9388.315	8296.284	6318.794	12340.608	74653.171
E07000042	7534	4277	3803	4656	5620	5247	7684	38821	8127.638	4411.843	4505.584	4786.538	5227.47	4935.803	12393.955	44388.83
E07000044	6836	4310	3353	4196	6143	6274	9518	40630	7237.296	4272.369	3586.366	4058.273	5022.232	5452.633	14591.406	44220.571
E07000045	10770	6409	6015	6951	9315	8540	13562	61562	12357.012	6708.943	6908.658	7741.676	8730.283	8409.385	21703.446	72559.405
E07000047	4480	2578	2462	2862	4131	3892	6046	26451	4920.171	2455.792	2651.747	3013.196	3688.894	3834.679	10067.704	30632.182

Area_code	F2014_chn	F2014_16-25	F2014_26-35	F2014_36-45	F2014_46-55	F2014_56-65	F2014_65p	F2014_all	F2039_chn	F2039_16-25	F2039_26-35	F2039_36-45	F2039_46-55	F2039_56-65	F2039_65p	F2039_all
E06000026	22487	20792	17315	15720	17400	14335	23539	131588	24304.569	22908.646	17061.008	14765.346	15474.603	13965.554	33537.283	142017.012
E06000027	10783	6769	6843	7714	9809	9233	17501	68652	11605.35	6895.474	6960.454	6984.828	8450.781	9043.309	25511.349	75451.546
E07000040	10165	5875	5696	7755	9804	10022	21203	70520	11671.127	6087.3	5965.453	7368.062	9285.645	10275.741	30814.32	81467.651
E07000041	9423	13279	8954	7137	7425	6105	10727	63050	10656.056	14386.26	9274.645	7541.637	7519.965	6267.724	15125.528	70771.815
E07000042	7080	3914	4078	4919	6045	5437	8904	40377	7628.956	3927.261	4298.81	4646.148	5321.96	5243.364	13818.404	44884.905
E07000044	6609	3522	3456	4841	6936	6832	11282	43478	7113.378	3604.795	3494.002	4509.951	5826.949	6225.517	16739.565	47514.155
E07000045	9933	6107	6086	7568	9953	9379	16769	65795	11301.549	6015.38	6778.114	7632.411	9019.813	9218.763	26047.586	76013.617
E07000047	4218	2403	2401	3139	4360	4194	7094	27809	4633.06	2334.913	2631.172	3028.525	3804.44	4130.16	11700.138	32262.408

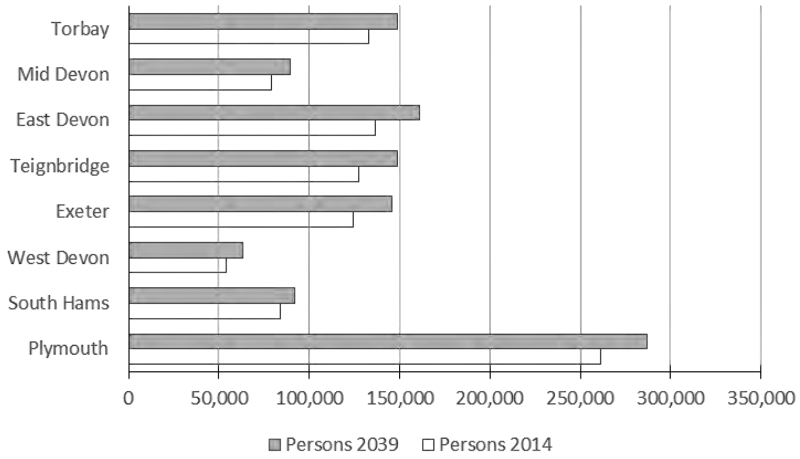


Figure B1. Population change mid-2014 to mid-2039 for local government areas in Dartmoor's hinterland. (Source: ONS 2014, SNPP Z1)

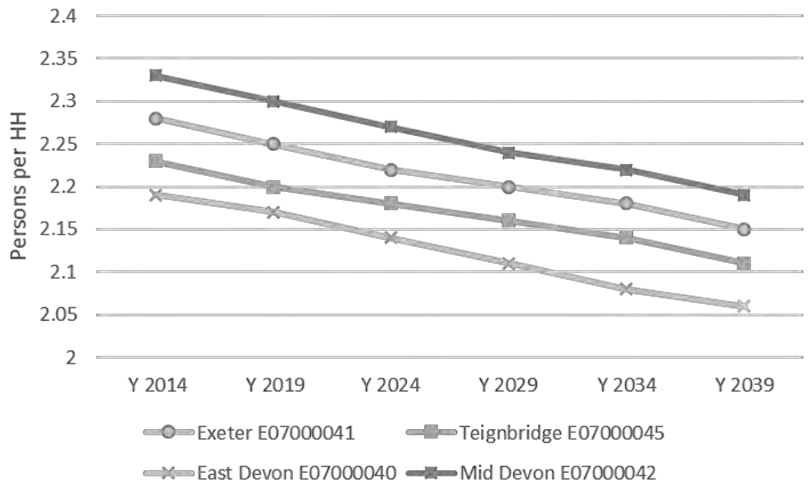


Figure B2. Household (HH) size in Exeter and surrounds decreases over time (source: DCLG 2016).

Table B3. Household (HH) information at a local government area level (HH available at an annual resolution, HH size on a five-year time step and HH with children (derived) available for 2014 and 2039 only). Source: ONS Live tables on household projection (2014-based). *Dartmoor's hinterland

Area code	Area name1	Area name2	Area name3	HH_2014 (000s)	Pop_2014 (000s)	HH_w_chn_2014 (000s)	Av_HH_Size_2014	HH_2039 (000s)	Pop_2039 (000s)	HH_w_chn_2039 (000s)	Av_HH_Size_2039
E92000001	ENGLAND			22746.487	53351.232	6555.474	2.35	28003.598	62026.7	7554.744	2.21
E06000026		Plymouth UA*		111.987	256.174	30.207	2.29	126.068	280.341	33.906	2.22
E06000027		Torbay UA*		60.307	129.949	14.634	2.15	71.276	144.18	16.586	2.02
E10000008		Devon		332.864	746.504	80.714	2.24	402.909	853.717	92.899	2.12
E07000040			East Devon*	60.972	133.393	13.802	2.19	76.147	156.64	16.067	2.06
E07000041			Exeter*	51.837	118.408	12.321	2.28	64.558	138.994	14.623	2.15
E07000042			Mid Devon*	33.602	78.288	9.084	2.33	40.16	87.935	9.974	2.19
E07000043			North Devon	40.663	91.97	10.397	2.26	46.144	99.538	11.457	2.16
E07000044			South Hams*	37.69	82.774	8.988	2.2	42.897	89.799	9.945	2.09
E07000045			Teignbridge*	55.788	124.422	13.804	2.23	68.303	144.313	16.351	2.11
E07000046			Torridge	28.922	64.643	6.859	2.24	36.081	75.934	8.294	2.1
E07000047			West Devon*	23.39	52.606	5.459	2.25	28.619	60.564	6.188	2.12

Appendix 3. Key species questionnaire

sweep

Recreation Impacts Project
Dartmoor key wildlife species questionnaire

Background information:
This questionnaire is part of a project between SWEEP (sweep.ac.uk) and the Dartmoor National Park Authority. In order to assess potential conflicts between key species and recreational activities, we are aiming to map locations of particular importance for key wildlife, and aim to understand potential impacts of recreational activities. In this questionnaire, we ask you to give us your expert opinion on key Dartmoor sites for "your" species on Dartmoor, and ask you to describe any potential impacts and possible mitigation measures for a range of recreational activities. Thank you very much for your help in this project.
For any questions or to submit this questionnaire, please email Sara Zonneveld: s.zonneveld@exeter.ac.uk

Species: ....

Species expert name: ....

Date: ....

SECTION 1: HABITAT AND DISTRIBUTION

What are the site-specific requirements of this species relevant to Dartmoor? Describe habitat and vegetation requirements, altitude, food resources, etc.

What is the current population size and population trend on Dartmoor?

What is this species' distribution on Dartmoor? Please describe. If you are able/willing to share any openly availably GIS data, please send this to s.zonneveld@exeter.ac.uk.

Are there specific areas on Dartmoor which are of particular importance for this species? If so, ***where*** (exact location and size of area) and ***why*** (e.g. higher numbers, better reproductive success)? Note: we are aiming to use the information for this question to produce species "hotspot" maps to indicate sites of wildlife importance. Please describe sites in detail, and if possible include grid reference or share any available data by emailing s.zonneveld@exeter.ac.uk

SECTION 2: RECREATION IMPACTS

Which, if any, recreational activities currently impact on this species, and - what effects are these recreational activities having (e.g. mortality/reduced population size, behavioural changes/displacement, reduced reproductive success, positive effects) - are there any specific sites on Dartmoor at which this impact is more severe, or is it the same across this species' Dartmoor range?		
ACTIVITY	IMPACTS ON SPECIES	SITES OF IMPACT
Cars on roads		
Walking/hiking (no dogs)		

Dog-walking		
Running		
Mountain biking (off-road)		
Horse-riding		
Kayaking		
Any indirect effects, for example an effect on food sources or associated habitat) (please describe)		
Large organised events such as walks/runs (please describe) …………………………		
Other (please list) e.g. camping, picnics, barbecues, on-road cycling, climbing, swimming, fishing …………………………		
Other (please list) …………………………		
Other (please list) …………………………		

Could future changes in recreation pressure affect this species (e.g. increased visitor numbers, changes in the recreational hotspot sites, changes in nature of recreation such as more large events)? Please describe these changes and potential impacts on this species.

SECTION 3: MITIGATION MEASURES

MITIGATION MEASURE: Please identify and describe any mitigation measures that could be put in place to prevent impacts of recreation on this species on Dartmoor. What are these measures and where might they be effectively applied? Examples of mitigation measures include changes/restrictions to access, change in location of facilities such as car parks/toilets, outreach activities. IMPLEMENTATION LOCATION: For each mitigation measure, please indicate where this mitigation measure should be implemented, e.g. across the entire Dartmoor range, in certain hotspots, in areas of particular concern. Please name specific locations on Dartmoor wherever possible. WHEN: When should these mitigation measures be implemented? E.g. as soon as possible, or when visitor pressure changes in the future. Should these measure be implemented year-round, or in specific months?		
MITIGATION MEASURE	IMPLEMENTATION LOCATION	WHEN

SECTION 4: OTHER

Are there any threats, other than recreational impacts, which you think need to be considered for this species on Dartmoor, either currently or in the future? This could include for example future climate change and habitat/land-use change.

Any other comments and/or concerns.

Appendix 4. Species case studies

On the following pages case studies on recreational impacts, derived from questionnaires with local species experts, are presented for each key species. For plants and butterflies, all key species are combined into one plant section and one butterfly section due to high similarity in recreation impacts for these groups of species. Species or species groups are presented in alphabetical order. NOTE: sensitive information on, such as maps and references to specific hotspot sites has been retracted. Full information was made available to DNPA in a full version of this report. Names of experts and organisations who provided information and data can be found in the full version of this report.

ADDER

Requirements and distribution

On Dartmoor, habitat requirements for adders are mature heathland areas, stands of mature gorse and bramble patches. This provides the requirements for shelter, overwintering and breeding sites, but adders forage more widely over Dartmoor. Adders overwinter in underground retreats often in areas of raised ground. Adders feed on lizards, small mammals, ground-nesting bird eggs and nestlings. The population size of Adder is not well established and needs further researching. The highest population densities are found on the lower reaches of Dartmoor where suitable habitats are located.

Recreation impacts

Most recreation activities are unlikely to strongly impact on Adder. Walking and hiking are unlikely to disturb adders as they are usually not found on paths. Where roads are located near suitable Adder habitats, adders are occasionally killed by cars, but strong impacts from increased numbers of cars on roads are unlikely. Some disturbance from large events is possible if large numbers of individuals visit key Adder breeding areas. The only other disturbance to adders is caused by dog-walking, with individual adders being disturbed by dogs during the spring and summer season. As dog-walking increases with increasing visitor numbers, dog-adder interactions are likely to increase, which may result in associated bad press, with adders being perceived as a threat to dogs and people. Conflict between adders and people can be reduced by restricting access to known breeding/overwintering areas, and by educating the public to avoid areas where Adder are known to occur. Keeping dogs on leads would avoid dog-adder conflict. Better mapping of adder populations across Dartmoor would help public education and management decision-making by identifying sites of potential conflict.

Other threats

The main threat to adders on Dartmoor is likely to be poor vegetation management. In areas known to harbour Adder, extensive burning of mature gorse and bramble patches needs to be avoided, and over-wintering sites need to be protected.

Hotspots

Examples of areas important for Adder include Bone Hill, Holne Moor, Haytor and Warren House. These are just examples of areas of importance for Adder, many other hotspot sites are likely to exist across the moor.

BOG HOVERFLY

Requirements and distribution

UK records for Bog Hoverfly are restricted to Dartmoor, with 17 sites currently known within the National Park. The species is elusive due to its low population density and fast flight, making population monitoring difficult. Anecdotal evidence from observations on Dartmoor since 1998 suggest that the species may have declined significantly, but this has not been proven due to surveying challenges. The species is not found on high exposed moorland; all known sites are on the eastern and southern fringes of the moor. The site characteristics consist of sphagnum bogs, particularly runnels, and spots with some shrub shelter. Adult Bog Hoverfly require a succession of bog flowers from May to September for nectar, key plant species are bog bean, bog pimpernel, common heather, marsh marigold and devils-bit scabious. Habitats grazed by cattle and ponies may be an essential requirement for this species. The larval ecology, and relationships to predators and parasitoids are currently poorly understood.

Recreation impacts

The Bog Hoverfly is found in wet habitat which are less frequented by visitors. Current recreational activities in the National Park are unlikely to have any direct impacts on this species.

Other threats

The species is associated with dung, and dung-associated flies may be particularly susceptible to the use of avermectins for de-worming livestock. On Dartmoor, levels of use of these chemicals are currently unknown, and further studies would be needed to understand the possible effects on Bog Hoverfly and other invertebrate species.

Hotspot map

Provided in full report

BLUE GROUND BEETLE

Requirements and distribution

This flightless beetle is found in humid, ancient oak and beech woodland with extensive moss cover. Within these woodlands, the species is usually found in wood pastures with little vegetation on the ground, managed by light grazing from sheep, ponies and cattle. Warmer, south-facing slopes are favoured. It feeds on slugs, and therefore requires good populations of *Limax* and *Lehmannia* spp. The Blue Ground Beetle is currently known to occur on six woodland sites on Dartmoor. The current population size is unknown, local monitoring since 1996 suggests populations on the six known sites appear to be stable.

Recreation impacts

It is unlikely that the Blue Ground Beetle suffers any significant direct effects from current recreational activities on Dartmoor, particularly when considering that most visitors in ancient oak woodland stay on paths.

Other threats

A spread of tree diseases, such as sudden oak death, to Dartmoor would have a severely detrimental effects on the Blue Ground Beetle.

Hotspot map

Provided in full report

BUTTERFLIES & MOTHS

Key species on Dartmoor include High Brown Fritillary, Marsh Fritillary, Pearl-bordered Fritillary and Narrow-bordered Bee Hawkmoth. This section combines information on these four species.

Requirements

The two main habitat types in which these species are found are Bracken slopes (**High Brown Fritillary** and **Pearl-Bordered Fritillary**) and wet grassland/rhôs pasture (**Marsh Fritillary** and **Narrow-Bordered Bee Hawkmoth**). Important features in Bracken habitats include steep, south-facing sides of valleys, as well as a Bracken vegetation interspersed with open areas and tracks (created by grazing animals). The presence of Violets, the food plant of these species, is a key requirement[1]. Marsh Fritillary and Narrow-Bordered Bee Hawkmoth are often found in the bottom of valleys in wet grassland. Sites need to have tussocky vegetation and some scrub or rush cover. Key plant species are Purple Moor Grass and Devil's-Bit Scabious.

Local distribution and trend

- **High Brown Fritillary** (stable but signs of recent declines): 12 sites across two areas of Dartmoor
- **Pearl-Bordered Fritillary** (stable): 40 sites across much of Dartmoor
- **Marsh Fritillary** (stable but signs of recent declines): 36 sites in multiple valley networks
- **Narrow-Bordered Bee Hawkmoth** (trend unknown): 8 sites across one area of Dartmoor

Recreation impacts

Generally, impacts of recreation are not a major concern for these species, but under substantial increases in visitor pressure the following impacts should be considered:

ACTIVITY	IMPACT
Collecting butterflies	On Dartmoor, (illegal) collection of butterflies has been reported and could pose a threat to these species
Cars on roads	Impact likely minimal, potential for mortality for small number of individuals flying across roads
Walking, dog-walking, running, horse-riding	There is potential for low levels of disturbance to individual butterflies, but unlikely to have population-level implications
Indirect effects - trampling	Under high visitor pressure, trampling of key vegetation or main foodplants could occur
Indirect effects - fire	Burning butterfly habitat through arson or fires could negatively affect these species

Other threats

Changes in habitat and land-use have had large negative effects on these species on Dartmoor. Appropriate grazing and habitat management is essential to ensure habitat connectivity. Changes in policy, such as future changes to agri-environment schemes are a key concern in the conservation of these species. Furthermore, climate change and eutrophication could impact these species through changes in vegetation and soils.

Hotspot map

Provided in full report

[1]*Fritillary Butterflies of Dartmoor, A practical guide to managing Bracken and Rhôs pasture habitats for Fritillaries on Dartmoor. Butterfly Conservation*

CUCKOO

Requirements and distribution

National surveys and the Devon Birds Atlas indicate rapid rates declines in recent decades. Declines in lowland areas have been faster, resulting in Dartmoor being of key importance to local Cuckoo populations. The main Dartmoor host of the Cuckoo is the Meadow Pipit, and Cuckoos are therefore generally found across open moorland habitats suitable to Meadow Pipit, although an additional requirement is the availability of perches (trees or high scrub) for calling and observing Meadow Pipit nests. This need for perches means that Cuckoo are generally not found breeding on the highest, most open parts of the moor. Cuckoos can also be found foraging in woodland areas.

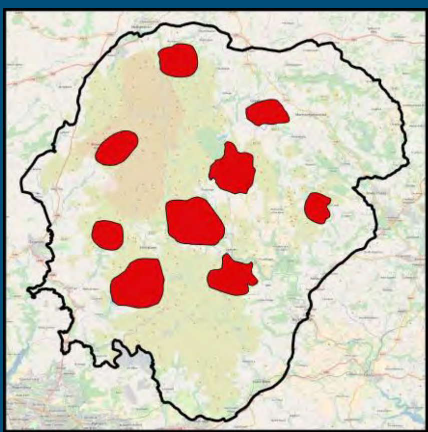
Recreation impacts

Increased visitor numbers would result in a higher frequency of disturbance. If this disturbance is constant throughout the day, for example along popular footpaths, this may interfere significantly with Cuckoo breeding and foraging behaviour.

ACTIVITY	IMPACT	SITES OF IMPACT
Cars on roads	A small chance of road collisions	Cuckoo hotspots near roads
Walking and hiking	Disturbance. Compared to other bird species, Cuckoos are relatively easily disturbed, and can flush at distances of 100+ meters, with some individuals much more sensitive from disturbance	Particularly on open moor, Cuckoos are less likely to flush from large distances in areas of high cover
Dog-walking	Cuckoos are much more sensitive to disturbance when dogs are present, increasing flushing distance. Young fledgling Cuckoos may be particularly vulnerable due to poor flight abilities	At Cuckoo breeding hotspots, where "dogs on lead" policy should be particularly strongly enforced
Running	Effects are likely similar to walking	Breeding sites
Mountain-biking	Causes less disturbance than walking	Breeding sites
Large organised events	Prolonged disturbance from walkers and runners could lead to prolonged Cuckoo displacement, which is likely to interfere with foraging and nest observation	Breeding sites

Hotspot map

The map shows known hotspots for breeding Cuckoo.



Other threats

Land management changes, such as increased grazing and burning pressures result in a reduction of essential Cuckoo landscape features like perches and heather-rich foraging sites. Habitat diversity should be encouraged to support this fast-declining species

DARTFORD WARBLER

Requirements and distribution

Dartford Warbler are a nationally important breeding bird species. They are classed as Near Threatened on the global IUCN red list. Populations of Dartford Warbler are increasing strongly in the UK and their range is expanding.[1] It is predicted that the UK will become an increasingly important stronghold for this species due to climate change causing a loss of suitable habitat in Europe.[1]. In 2006, 31 territories on Dartmoor represented a nationally important population, but in line with Dartford Warbler nationally, this number crashed due to cold winters of 2009/10 and 2010/11.[1] Dartmoor currently holds a small population.

Recreation impacts

Dartford Warbler is a species which is known to be impacted by recreation. Studies have shown that human disturbance can prevent multiple breeding attempts, thereby reducing reproductive output.[3] Increased footfall is therefore likely to cause increased pressure on Dartford Warbler populations. Large events and activities such as picnics and camping are likely to have additional harmful effects by causing prolonged disturbance when carried out near Dartford Warbler territories. These activities may also impact on range expansion, preventing birds from settling in areas of suitable habitat when footfall levels are high. To ensure recreation impacts to Dartford Warbler (and other breeding birds) are minimised, the public needs to be educated to avoid areas where birds are alarming. Access restrictions can be used at known breeding sites (e.g. as known from Devon Birds Atlas) to prevent reduced breeding success. Murison (2007)[3] found that 13-16 individuals passing through a heath territory per hour would prevent multiple broods. Although this result was not based on Dartmoor data, and only covers a specific habitat type, this number could be used as an indicator for sites where access restrictions may be needed (i.e. breeding areas where footfall exceeds this number).

Hotspot map

Dartford Warbler are found mostly around the southern, south-western and south-eastern edges of the moor. The population size is very small, and therefore this species currently has no specific hotspots with high densities of Dartford Warbler.

Other threats

Dartford Warbler require heathland and mature gorse, and therefore active habitat management is needed. In areas where Dartford Warbler have been known to occur, extensive burning of mature gorse needs to be avoided. To protect and enhance the population of this rare breeding birds, and to ensure range expansion, habitat management is needed to ensure improved habitat connectivity across Dartmoor.

[1]*The State of the UK's Birds 2017*

[2] *http://devonbirdatlas.org*

[3] *Murison (2007) Ibis 149 (s1)*

DIPPER

Requirements and distribution

Dipper are found along fast-flowing streams and rivers. Their main requirements are the availability of suitable nesting sites, as well as clean water to fulfil feeding requirements. They are highly territorial species, regularly found nesting in man-made structures such as bridges. Purpose-built Dipper nestboxes are available, for example for use on bridges which lack existing nesting opportunities. On Dartmoor, Dipper are found along all larger rivers, and birds are known to also spend time at higher altitudes, including along leats on the open moor. The 2016 State of the UK Birds report indicates population declines of 28% across the country, which is in line with breeding declines seen locally (see for example devonbirdatlas.org).

Recreation impacts

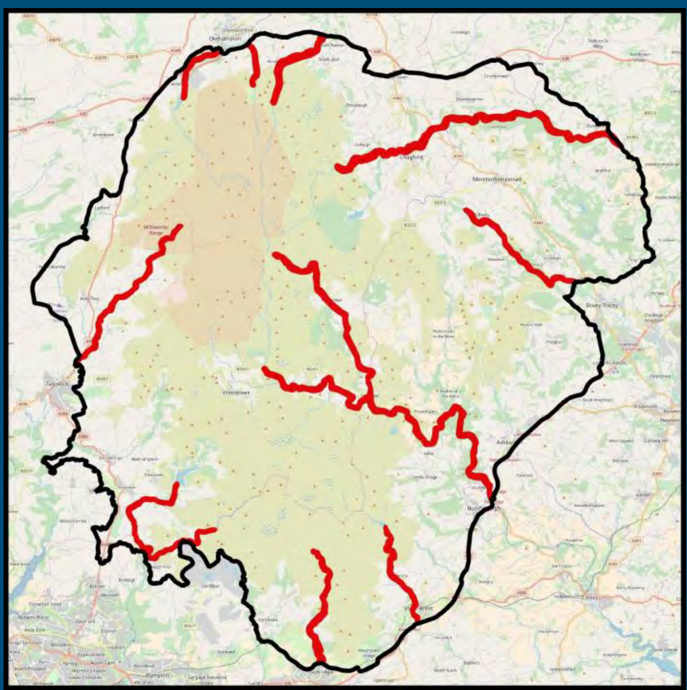
Dipper frequently breed on foot bridges and in areas frequented by humans, and appear relatively tolerant to people, for example walkers crossing over bridges with nest-sites. As dipper typically nest over flowing water, they are relatively undisturbed by dogs, especially when nesting on Dartmoor bridges. The main recreation impact for dipper is likely to result from water-based activities such as kayaking; the Dipper's territorial nature means that kayaking could disrupt territorial behaviour and foraging, and could disturb young fledgling birds. Threshold levels of disturbance are currently unknown, but increased intensity of kayaking could lead to prolonged disturbance and therefore have negative effects on this species.

Other threats

Clean water is essential for Dipper and therefore any deterioration in water quality, including increases in sediment load, would be a cause for concern.

Hotspot map

All major rivers on Dartmoor support Dipper.



DUNLIN

Requirements and distribution

Dunlin are small waders found breeding in the uplands. They used to be red-listed in the UK but was recently moved to Amber status following improvements in their population status.[1] A small population of around 20 pairs is found on Dartmoor from April to September.[2] Their breeding habitat generally consists of very wet, boggy ground with open water pools and peaty hollows at the higher altitudes on Dartmoor. They are site-faithful and return to breeding sites across years.

Recreation impacts

ACTIVITY	IMPACT
Walking	Walking could cause disturbance to breeding pairs. Due to the remoteness of Dunlin breeding sites, current recreation levels are not an issue as only small numbers of individuals frequent Dunlin breeding areas.
Dog-walking	As with other Dartmoor ground-nesting bird species, dogs have the potential to cause breeding disturbance in this species, although this is not currently thought to be a concern due to the remoteness of Dunlin breeding sites.
Large events	Large events could cause serious disturbance. Policy to prevent disturbance from organised events to breeding sites from April – August is essential

Other threats

Short vegetation is necessary and should be maintained through grazing. Mire restoration work has been beneficial. Crow predation is a concern; crows may be observing and targeting Dunlin (and potentially other moorland bird) nests.

Hotspots

Provided in full report

[1] *The State of the UK's Birds 2016*

[2] *http://devonbirdatlas.org*

FAIRY SHRIMP

Requirements and distribution

Fairy Shrimp are Crustaceans found in temporary pools which tend to have little aquatic vegetation and muddy bottoms. These pools can be dips in open grassland, but also wheel ruts and puddles by car parks. Fairy Shrimp are found on Dartmoor, mostly in pools located at 180-200 meters in altitude. Relatively high grazing levels, particularly by ponies, appears to be important for pool maintenance and egg transfer. No exact population estimates are available, but 20 years of intermittent recording has shown Fairy Shrimp have occurred in pools in 10 localised areas. The species is protected under the Wildlife and Countryside Act 1981.

Recreation impacts

Activities such as cars, mountain biking and large organised events may have mixed effects. These activities may help the species by keeping pools open. On the other hand, too much disturbance, such as cars driving through pools, could have adverse effects. It is unlikely that moderate changes in recreation pressure will affect this species, although localised effects at specific sites could result from recreation-related changes in pool creation and disturbance rate.

Other threats

Appropriate grazing levels need to be maintained to ensure habitat availability and egg dispersal for Fairy Shrimp.

Hotspots

Provided in full report

[1]*https://www.legislation.gov.uk/ukpga/1981/69/schedule/5*

GREATER HORSESHOE BAT

Requirements and distribution

Greater Horseshoe Bats can be found roosting in caves, mines, old slate-roofed barns and buildings with gaps of more than approximately 45cm. Their foraging and commuting requirements include linear features, woodland edges, hedgerows, meadows and cattle-crazed habitats. They feed on a range of insects such as moths, dung beetles and craneflies.[1] There are limited numbers of maternity colonies in the UK. In Devon 11 priority areas were identified, with the South Hams holding a significant proportion of the UK population.[2] Greater Horseshoe Bats are found along most of the edge of Dartmoor, and within the boundary of the National Park are a number of larger towns.

Recreation impacts

ACTIVITY	IMPACT
Caving	Potential negative impacts from disturbance at sites where bats are roosting or hibernating
Cars on roads - collision	Greater Horseshoe Bat fly close to the ground and are therefore vulnerable to vehicle mortality[3]
Cars on roads - disturbance	As Greater Horseshoe Bats are light-sensitive, traffic at night can cause disturbance to commuting bats
Other activities (e.g. walking, cycling, kayaking)	Although generally these activities are unlikely to cause issues, any activities close to roosts or at night with torches would be a potential concern

Other threats

Increases in night-time lighting, for example during large events or through changes in infrastructure and street-lighting, can cause severe detrimental effects by impacting bat commuting routes. Land-use change resulting in losses of foraging sites and commuting routes are a further threat. Loss of meadows, pastures and grazed areas could have negative effects by causing a reduction in important invertebrate prey species.

Hotspot map

Provided in full report

[1] *Greater Horseshoe Bats factsheet. Devon Greater Horseshoe Bat Project. www.devonbatproject.org*

[2] *South Hams SAC - Greater horseshoe bat consultation zone planning guidance. Natural England (2010)*

[3]*Medinas (2013). Ecological research. 28 (2)*

HEN HARRIER

Requirements and distribution

The Hen Harrier is a rare and declining bird of prey. Population surveys estimated approximately 575 pairs across the UK.[1] On Dartmoor, Hen Harrier are almost exclusively a winter visitor; up to eight birds are generally seen between September and April. Hen Harrier forage over much of the open moor; they tend to prefer areas of heath and lightly grazed grass moor. Their prey includes small mammals, as well as passerine species such as Meadow Pipit[2].

Recreation impacts

As a wintering species, Hen Harrier are perhaps less affected by recreational pressures by using the moors at a time of year when visitor pressure is generally lower. Generally, Hen Harrier and recreational activities do not come into conflict. The only serious threat to this species is disturbance of roost sites by birdwatching activity. Such disturbance has been known to occur on Dartmoor. Therefore, roost site information is currently only shared with organisations and individuals involved in the management of this species and its sites.

Other threats

Should Hen Harrier start breeding on Dartmoor, recreation impacts would need to be re-considered and appropriate protection put in place. Continued appropriate vegetation management (prevention of swaling) at roost sites is also key.

Hotspots

Hen Harrier use large areas and can forage across most of Dartmoor. The central area of the moor provides important hunting sites. Disturbance to roost sites by members of the public is a key concern. Information on current and past roost sites is not included in this report, but is already known by key organisations and land owners to ensure appropriate land management and protection.

[1] *The State of the UK's Birds 2017*

[2] *Clarke (1997) Ibis 139 (1)*

NIGHTJAR

Requirements and distribution

Nightjar are ground-nesting birds breeding mostly on heathland and in forestry plantations.[1] The species has showed declines across the UK, but conservation action in recent years has resulted in it being moved from Red to Amber status.[2] The Devon Birds Atlas indicates a range increase over recent decades. On Dartmoor Nightjar particularly thrive in recent clear fells within forestry plantations.

Recreation impacts

Human impacts on Nightjar have been established in several studies. It has been shown that human disturbance can cause nest failure by through predation when adults are flushed and nests are left exposed; a Dorset study showed that failed nests were located closer to paths.[3]

ACTIVITY	IMPACT	SITES OF IMPACT
Walking and hiking	Disturbance by walkers can lead to an increase in nest failure (see further detail in study by Langston)[3]	Breeding sites
Dog-walking	See above link between flushing increased nest predation, dogs could potentially exacerbate disturbance effects. Flushing of Nightjar by dogs has been confirmed on nest cameras [3]	Breeding sites
Running	Effects are likely similar to walking, potentially less severe due shorter disturbance time	Breeding sites
Mountain-biking	Disturbance caused by increased intensity of off-road cycling in conifer plantations is a concern	Breeding sites
Illegal parties	Illegal raves with very large numbers of individuals (1000+) have previously taken place at known Nightjar hotspot sites, leading to severe night-time disturbance and potential nest destruction from trampling	Particular hotspot sites

Other threats

Habitat and land-use change are a threat to this species; Nightjar require specific vegetation types within heathland and forestry, and the maintenance of appropriate vegetation conditions is essential for this species.

Hotspot map

Provided in full report

[1] *BTO Research Report No. 398.*
[2] *The State of the UK's Birds 2016*
[3] *Langston et al. (2007) Ibis. 149.*

OTTER

Requirements and distribution

Otters are found on rivers, streams and lakes across Dartmoor. Their main requirement is the availability of fish prey (although they are known to prey also on frogs, riparian birds and rabbits). The population is thought to have been at carrying capacity for the last 20-30 years, having recovered from a previous nationwide decline. The exact number of individuals on Dartmoor is unknown; the Otter's territorial nature and large home ranges (up to 40km for males) means that total numbers are not high.

Recreation Impacts

Otters generally are tolerant of human activity, and can habituate to human recreational activities. Otters are killed on roads, but it is thought that casualty rates are not currently impacting on long-term population trends. Excessive levels of traffic around water reaches is likely to lead to increased road casualties. Potential indirect effects, such as effects on fish supply or the effects of toxic chemicals, should be kept in mind. Current requirements for ecological impact assessments are in place as part of the planning system, and the Mammal Society is currently preparing further guidance which is expected to be published in 2019.

Other threats

Any factor which may lead to a reduction in fish populations, as well as any introductions of new forms of toxic chemicals, for example through changes in farming practices.

Hotspots

There are no known particular hotspots for this species, although it is worth noting that there will be specific sites of importance where Otters give birth and rear young.

PEREGRINE FALCON

Requirements and distribution

A small number of Peregrine Falcon pairs breed in and around Dartmoor, for example in some quarries. The UK population size was estimated to be around 1769 pairs[1] in 2014, with the Dartmoor population currently stable at around seven pairs (pers. comm.).

Recreation impacts

Scientific research has shown Peregrine Falcon breeding success is impacted by disturbance, for example from climbing activities.[2] However, as Peregrine Falcon on Dartmoor mostly breed on private site with no public access, climbing impacts are not currently a concern. Change of land-use, for example use of quarries for outdoor activities, could impact Peregrine Falcon breeding activity and success. A large reduction of recreational activity could result in Peregrine breeding on some of the larger tors on the open moor.

Other threats

In addition to rock climbing, the IUCN red list describes persecution, habitat degradation and wind energy developments as key threats.[3]

Hotspots

Birds breed in and around Dartmoor. Information on exact breeding sites is kept out of the public domain due to the risk of illegal persecutions.

[1] *Wilson (2018) Bird Study (online)*
[2] *Brambilla (2004) Ardeola. 51 (2)*
[3] *www.iucnredlist.org Peregrine Falcon*

PLANTS

Dartmoor National Park is home to a wide range of scarce and/or ecologically important plant species. On the open moors, bogs and grasslands, important species such as Vigur's Eyebright and Bog Orchid are found growing. Flax-leaved St John's Wort, for which Dartmoor holds the majority of the British population, is found on rocky slopes.[1] Mosses, liverworts and lichen thrive on bare, unburn heathland, on tors and rocks (e.g. *Bryoria* spp.) and on isolated Hawthorn trees. In woodland environments, lit conditions, glades and ride edges are important (e.g. *Lobaria* and *Stricta* spp.). Examples of notable lower plant species on Dartmoor include the charismatic String of Sausage lichen and the UK BAP species *Graphina pauciloculata*.

Recreation impacts[2]

The potential impacts of recreational activities on plant species were not investigated on a species by species basis for this project, the table below provides a generic overview of recreational activities and their potential impacts on Dartmoor plants. Low levels of recreational activity are unlikely to cause significant impacts, but sensitive species and habitats could be severely impacted by increased recreational activities. Large organised events could lead to particularly severe damage due to sustained, increased trampling effects on event routes. Increased recreational pressures could lead to increased damage to lower plant species growing on tors.

ACTIVITY	IMPACT
Cars on roads	Increased numbers of cars would detrimentally affect air quality
Walking, hiking and running	Trampling damage. Large events may result in particularly severe trampling damage
Dog-walking	Nutrification and trampling
Mountain-biking	Off-road cycling is likely to be one of the most damaging activity types for a range of plants due to "trampling" pressure
Horse-riding	Trampling damage
Kayaking, swimming & fishing	Trampling at access points and partial loss of lower plant species from stones
Letterboxing and geocaching	Partial loss of lower plants from stones
Fires and barbecues	Complete loss of plants at burning sites

Other threats

Changes in grazing regime can negatively impact plant communities, long term low-level grazing is to be preferred over heavy grazing. Furthermore, decreased air quality and changes in agricultural practices can have negative impacts. Other concerns include increased shading and ivy growth on trees and tors, as well as scrubbing up of open heath and tors. A lack of management of important plant sites was highlighted as a further threat in species questionnaires.

Hotspots

Key plant species are found across all moorland habitat types. Species-specific distribution information can be found for example in A New Flora of Devon (Smith, Hodgson & Ison 2016).

[1] *The State of Dartmoor's Key Wildlife 2011*

RAVEN

Requirements and distribution

These large omnivorous corvids are widespread on Dartmoor, and populations are increasing.[1] They feed on a wide range of prey items, including carrion, rabbits, eggs and birds, and have been reported to occasionally kill lambs. Raven nest on tall trees in woodlands, as well as on remote tors.

Recreation impacts

The only recreational activity that is of any significant concern is rock climbing. Climbing on tors with breeding Raven during spring causes disturbance to breeding Raven. Most hiking and dog-walking is thought to have little effects, although increasing numbers of visitors to woods and remote tors during spring is a concern and the potential for future impacts should be highlighted. This is of particular concern because Raven start breeding early in the season when few people are visiting, resulting in nest desertion when visitor disturbance at remote breeding sites increases later in the breeding season.

Hotspots

Raven are widespread across Dartmoor. During the breeding season, birds are found breeding in woodlands, on remote tors and likely also in quarries.

Map with examples of breeding tors provided in full report.

[1] *See The State of the UK's Birds 2016 and http://devonbirdatlas.org/*

RED GROUSE

Requirements and distribution

Red Grouse are a resident species on upland heather moorland. They are territorial through much of the year, and feed mostly on heather shoots, along with other plants (e.g. Cotton Grass and Bilberry), as well as invertebrates for chick-rearing.[1] The exact current population size on Dartmoor is not known and difficult to estimate, but is probably are in the region of a maximum of 50 breeding pairs. Birds are distributed relatively widely across Dartmoor, mostly found at altitudes of over 450m.

Recreation impacts

As most Red Grouse on Dartmoor are found mostly in the more remote areas, they are currently relatively protected from recreational impacts. In those areas, they are unaffected by cars on roads and unlikely to be affected by hikers, runners and horse-riders. However, Red Grouse are flushed by dogs, and dog-walking is a concern in some Dartmoor areas of high footfall where grouse are known to occur. Furthermore, large events during the breeding season with any off-track activity would be a concern for this species.

Other threats

Red Grouse require young heather for feeding, appropriate vegetation control is therefore needed to support this species.

Hotspots

Provided in full report

[1] *Martınez-Padilla (2013). Journal of Animal Ecology. 83 (1)*

RING OUZEL

Requirements and distribution

Dartmoor holds the UK's most southerly breeding population of Ring Ouzel , a UK red-listed species which is showing severe population declines.[1] Breeding habitat requirements include the presence of "steep sided river valleys, tracts of broken ground with boulders, bracken, gorse and bilberry".[2] On Dartmoor, they are mostly found on the north-west side of the moor. Long-term survey data on population trends on Dartmoor is limited, but suggests numbers are declining from a possible 20-25 pairs in the nineties. Monitoring efforts in recent years have showed numbers continuing to decline from 10-12 pairs in 2010-2012 to 6-7 pairs in 2017.

Recreation impacts

Extensive observations of Ring Ouzel breeding behaviour on Dartmoor has provided detailed insights into impacts of recreation on this species. Visitor pressure already impacts significantly on this species, and key concerns under future increased visitor numbers include:

- Expansion of climbing areas, new climbing areas being used and/or promoted in guides
- Increase in bouldering and river-related outdoor activities
- Increased commercial dog-walking, wild camping and geo-caching

ACTIVITY	IMPACT	SITES OF IMPACT
Walking and hiking	Nesting on tors appears to have decreased in recent years and is thought be linked to disturbance. Females are easily flushed (from within +-20m), and therefore on popular tors this result in substantial breeding disturbance. Regular flushing of birds has been observed to lead to nest failure through predation through birds revealing nest site to predators.	*Provided in full report*
Dog-walking	As above, bird behavioural change and disturbance is a major concern. Mortality has not been observed but direct nest disturbance has occurred. Particular concerns are around fast-moving and shoot-related breeds of dogs, as well as commercial dog-walking and/or owners exercising large numbers of dogs (up to 16 dogs with one owner observed on one Ring Ouzel breeding site)	*Provided in full report*
Climbing and bouldering	Current breeding distribution does not overlap with popular climbing sites, but would cause disturbance, displacement and/or reduced reproductive success. Bouldering has been observed occasionally near breeding sites, and high frequency bouldering during the breeding season should be avoided.	All breeding sites
Running and mountain-biking	Likely to be of lower impact due to fast, short-term disturbance, but larger numbers over prolonged would be a concern	All breeding sites
Drones and model airplanes	Currently unknown, but should be controlled to prevent potential impacts	All breeding sites

TABLE CONTINUED ON NEXT PAGE

[1] *The State of the UK's Birds 2017*

[2] *Emergency Action for Dartmoor's Ring Ouzels (Turdus torquatus). Productivity & habitat assessment Dartmoor 2011. Nick Baker & Fiona Freshney*

RING OUZEL (continued)

ACTIVITY	IMPACT (continued)	SITES OF IMPACT
Geocaching and letterboxing	Individuals can spend hours in one area, searching for caches in rocks and crevices where Ring Ouzel (and other species like Wheatear) would nest. Has been observed to lead to 1h+ disturbance of Ring Ouzel fledgling feeding. Small scale letterboxing likely minor issue.	Potential for disturbance across sites.
Large events	Current policies within DNPA ensure that disturbance from large organised events is minimised. Other unofficial events with large numbers of individuals are a concern, especially when time spent in breeding area is prolonged (e.g. group barbeques, camping)	All breeding sites
Camping, barbecues, picnics, swimming	Prolonged disturbance from these activities prevents the pair leaving and attending nest sites. Causes displacement and reduced breeding success. Camping has been observed near breeding sites (included at banned sites). On one instance, litter from party was jammed into a nesting crevice, in this instance this took place shortly after fledging but the anecdote reveals the potential implications of such activities.	All breeding sites
Naturalists and surveyors	Regularly observed. Can cause displacement and reduced breeding success. Individuals have been observed visiting nests, disturbing birds, and trampling vegetation around nest site.	All breeding sites.

Other threats

Other concerns for Ring Ouzel conservation are climate change and vegetation management. This includes continued (or increased) overgrazing of heathland habitat, undergrazing of forage grassland (resulting in *Molinia* dominance), and inappropriate swaling (e.g. of Western Gorse on steep breaks in slope). Army activity has both positive and negative effects. Army activity leads to temporary exclusion zones, thereby reducing disturbance from visitors. However, this has led to nest failure after birds have settled to breed in areas which were highly disturbed when sites were again open to the public. Therefore, the impact of army closures on Ring Ouzel settlement and success in relation to visitor hotspots needs to be considered. There have been occasional incidents from disturbance from firing and noise, resulting in reduced reproductive success and displacement of breeding birds.

Breeding sites

Provided in full report

[1] *https://data.gov.uk/dataset/rare-bird-nesting-areas*

SALMON

Requirements and distribution

Atlantic Salmon are found in all the main rivers of Dartmoor, and many areas of high spawning potential lie within the National Park. Salmon are of important economic value to the South West, for example, a study by the environment agency estimated that *"anglers' annual expenditure on fishing inland waters in the South West totalled about £100 million, supporting approximately 2,300 jobs and £50 million of household income"*[1]. The species has shown severe declines; numbers returning to English and Welsh rivers have declined by +-45% since the 1970s[2].

Recreation impacts

Rivers are an important recreational attraction on Dartmoor. Kayaking, wild swimming and river-side picnics are very popular along numerous areas of Dartmoor river. Previous research[3] highlighted that Salmon can *"be reluctant to pass obstacles that should not pose any physical problem"*. Therefore, obstructions such as smaller dams created by visitors could potentially impact Salmon when built at sensitive locations. Canoeing and kayaking are often raised as having potential negative effects, for examples through disturbance of Salmon redds. However, a literature search using key words such as *kayak, canoe, watersport* and *recreation* revealed no relevant studies exploring this issue through direct scientific study (as also outlined in EA R&D technical report W266[4]). Further scientific research appears necessary to understand whether these activities could have impacts on Dartmoor's Salmon. Illegal fishing is a further potential threat.[5] Indirect recreation impacts, such as changes in water quality (see below), for example through pollution or toilet systems leaking into rivers, need to also be considered.

Other threats

Thorstad (2008)[3] outlines a wide range of factors affecting Salmon migration, including changes in water temperature, pH and pollutants. Any potential river management which alters river flow could affect Salmon breeding.

Hotspots

Map with areas of high Salmon spawning potential provided in full report (based on past work by EA).

[1]*Economic evaluation of inland fisheries (2009). Environment Agency*

[2]*Assessment of Salmon stocks and fisheries in England and Wales (2017). CEFAS, Environment Agency and Natural Resource Wales*

[3] *Thorstad (2008). Rev Fish Biol Fisheries. 18*

[4] *Environment Agency R&D Technical report W266. Effects of canoeing on fish stocks and angling*

[5] *Atlantic Salmon Devon Biodiversity and Geodiversity Action Plan. Devon Biodiversity Partnership 2009.*

SKYLARK

Requirements and distribution

Skylark are found on areas of moorland and grassland with low, open vegetation for nesting. They breed at a very broad range of altitudes, ranging from lowland grassland to high open moor. They are very widely distributed on Dartmoor across all areas of suitable low vegetation. Skylark have declined strongly across the country, and Dartmoor (and Exmoor) appear to be strongholds with relatively large populations. A 2006 survey[1] estimated a total of 4,593 individuals on the North Moor alone.

Recreation impacts

Given the broad distribution of Skylark across Dartmoor, only large changes in recreational activity levels would be likely to significantly affect the population as a whole. However, national declines and the importance of Dartmoor for breeding Skylark should be kept in mind, and therefore potential impacts in response to recreation should be re-considered periodically.

ACTIVITY	IMPACT	SITES OF IMPACT
Walking/hiking	Skylark nest in very low, open or grazed ground, and birds can nest near or along paths. Trampling of nests is therefore a higher risk compared to other moorland birds. Compared to other upland birds, adult Skylark generally appear to be less sensitive to disturbance from walkers	Breeding sites near paths
Dog-walking	As most moorland birds, tends to be more disturbed by walkers with dogs. Nesting near paths means nests are likely to be more susceptible to dog disturbance	Breeding sites near paths
Running	Sole, occasional runner is unlikely to cause any issues (but see note on large events below)	Running routes
Horse-riding	Only potential issue would be of trampling risk, but this is likely of low concern due to large Skylark populations and relatively low numbers of riders	Along riding routes
Large events	Large, organised events, especially cross-country runs, could increase risk of trampling	Any event locations

Other threats

Maintaining suitable habitat types and supporting insect populations, for example through targeted vegetation management, is essential for supporting a thriving Skylark population.

Hotspots

Skylark do not have particular breeding hotspots on Dartmoor, they are ubiquitous across suitable grassland and moorland habitats.

[1] *Breeding Bird Survey of Dartmoor Training Area, MoD and RSPB, 2006*

SNIPE

Requirements and distribution

Snipe are primarily found in wet, boggy habitats. They feed on a range of invertebrates, and earthworms and crane fly larvae are thought to make up a large part of their diet.[1] Snipe are amber-listed in the UK, and the far majority of Devon's Snipe breed on Dartmoor. Devon Bird Atlas data shows increases in breeding numbers over recent decades.[2] Due to the Snipe's secretive nature, population estimates for Dartmoor are difficult to obtain, but are thought to lie in the region of approximately 90-100 breeding pairs.

Recreation impacts

Due to the Snipe's dependence on wet, boggy habitats, there tends to be little overlap between recreation sites and Snipe habitats. Therefore, there are no recreation activities on Dartmoor which are currently thought to have significant effects on this species.

Other threats

The key requirement for Snipe is wet, boggy habitat, and therefore any draining of wet bogs would have adverse effects on this species. Snipe is one of the species shown to be negatively affected by upland wind farms[3], therefore future development of such wind infrastructure in or around Dartmoor could negatively affect breeding bird densities.

Hotspots

Snipe are widely distributed across Dartmoor's valley bogs and wet ground at all altitudes. Any wet areas are potential important breeding sites.

[1] *Hoodless (2007). Bird Study. 54 (2)*

[2] *http://devonbirdatlas.org*

[3] *Pearce-Higgins (2012). Journal of Applied Ecology. 49 (2)*

SOUTHERN DAMSELFLY

Requirements and distribution

Southern Damselfly is a declining, endangered species of damselfly. The species has very specific habitat requirements.[1] It requires continuously flowing, unshaded runnels with emergent vegetation such as Bog Pondweed and Marsh St John's Wort. Specific pH conditions (affected by geological site characteristics), as well as optimal grazing regimes and clean water are essential. The species is found on three sites on Dartmoor, which have been monitored for the past 12-22 years. Further details of Dartmoor populations, requirements and distribution can be found in DNPA reports by Norman Baldock and Dave Boyce.

Recreation impacts

This species is unlikely to be severely impacted by recreational activities. One notable exception is joy-riding with motorised vehicles at one known site, which potentially threatens a runnel by damaging the turf near the spring that feeds the runnel. Roadside boulders were suggested as a mitigation measure. Furthermore, large numbers of runners, mountain-bikers or horse-riders would have adverse effects, but should be avoided through the DNPA large event monitoring. Such disturbance is unlikely due to the wet nature of the Southern Damselfly sites.

Other threats

Sufficient grazing at the correct sites is essential and needs to be actively managed. Other threats could include weather-related events, such as summer droughts which could dry up runnels with larvae.

Hotspot map

Provided in full report

[1] *Southern Damselfly Management Handbook. British Dragonfly Society (2016).*

WHINCHAT

Requirements and distribution

Whinchat breed on open moor and heathland, and are generally found breeding on the moorland fringes, rather than on high exposed moorland. On Dartmoor they have a wide, but scattered distribution across the lower moorland sites with suitable habitats. The habitat tends to consist of sloping ground with some vegetation cover. They are often found associated with Bracken and sometimes, but not exclusively, with heather cover. Whinchat are now red-listed in the UK and have suffered very strong nationwide declines, and BTO atlas data[1] show a northward and upland shift. Dartmoor, along with Exmoor and Salisbury Plain, is now an important southern stronghold, although national and local atlas data[2] shows substantial declines in Devon also.

Recreation impacts

Occasional disturbance is unlikely to affect nesting success (see for example Border et al. 2018[3]), but where visitor hotspots or busy footpaths are close to breeding sites, potential effects of disturbance on predation or nest abandonment need to be considered.

ACTIVITY	IMPACT	SITES OF IMPACT
Walking/hiking	Whinchat are more "flighty" than other moorland passerines such as Stonechat and Skylark, and is subsequently more easily disturbed	Nesting areas
Dog-walking	As with other moorland birds, Whinchat tend to be more sensitive to disturbance when dogs are present	Nesting area
Running	Likely similar to walking. Single disturbance events are unlikely to cause concern, but continued disturbance, e.g. for birds nesting close to busy footpath, may affect breeding behaviour	Nesting areas

Other threats

Bracken growth can be an important landscape feature for Whinchat, and should therefore not be strongly controlled in areas of Whinchat breeding. To avoid nest destruction as a result of vegetation management, Bracken control should wherever possible avoid the bird breeding season.

Hotspots

A comprehensive knowledge of particular breeding hotspots is not currently available, although some known areas of breeding importance are known from targeted studies. Whinchat are very faithful to their breeding sites, and therefore a data collation effort which combines known breeding site data (e.g. from RSPB surveys, BBS data and Holne Moor bird study) would be helpful in informing locations of Whinchat conservation importance where specific habitat and disturbance protections should be put in place.

[1] *BTO Bird Atlas Mapstore https://bto.org/mapstore/*

[2] *http://devonbirdatlas.org*

[3] *Border (2018). Ibis (online)*

WOOD WARBLER

Requirements and distribution

Wood Warbler are ground-nesting birds, found breeding in woodland areas with high canopy cover and a relatively open understory. Nest sites are often located on sloped ground. On Dartmoor, birds are mostly found in oak woodland, but are also known to breed in plantation woodlands. Across 27 monitored woodlands on Dartmoor, the total population size has shown a continuous decline from 150 in 2012, down to 48 in 2017 (RSPB survey). Previous to this monitoring effort, the population is likely to have been declining for several decades.

Recreation impacts

A main concern is population growth and the promoting of visiting reserves leading to increased numbers of visitors at key breeding sites. In light of these increases, a (temporary) redesign of rights of way or reserve paths should be a consideration.

ACTIVITY	IMPACT	SITES OF IMPACT
Walking, hiking and dog-walking	Territory settlement may be negatively affected by the presence of walkers and dogs. Anecdotal evidence on Dartmoor shows that in woodlands with increasing visitor numbers, birds no longer breed in busy areas despite birds being seen there pre-breeding. Those areas in the past did support active Wood Warbler territories	*See full report*
Mountain-biking	Mountain-biking is frequent in territories around some breeding sites, exact effects not yet studied	*See full report*
Large events	Past woodland visit days with several hundred visitors took place during the breeding season. People strayed off paths and were seen walking close to nests, which are highly disguised and therefore vulnerable to trampling	*See full report*
Information-sharing among photographers	Single wildlife photographers have no negative effects. However, in recent years photographers have been known to intentionally or unintentionally share details of nest locations on social media, leading to continued disturbance near particular nests. This was also observed for other woodland species such as Redstart	Any breeding site

Hotspot map

Provided in full report

Local Natural Capital Accounting: does it deliver useful management information?

A case study of Dartmoor and Exmoor National Parks

June 2020

Report to Exmoor National Park Authority and Dartmoor National Park Authority

Michela Faccioli
Sara Zonneveld
Charles Tyler
Brett Day

Acknowledgements:

The research in this report was funded by the Natural Environment Research Council (NERC) through the SWEEP project [grant number NE/P011217/1].

TABLE OF CONTENTS

1 INTRODUCTION

In the 25 Year Environment Plan the UK government has set out an ambitious program to achieve net improvements in England's environment over the course of this generation. After decades of environmental degradation, resulting often from neglecting natural capital in decision-making, the 25 Year Environment Plan represents an important step towards placing the protection of the environment at the top of the political agenda. The growing consideration of environmental issues in decision-making has been motivated by increasing evidence that environmental preservation is necessary to sustain and contribute to human well-being and economic prosperity. Natural Capital (or natural assets) - the bulk of habitats and ecosystems that underpin our natural environment - provide a variety of ecosystem goods and services (e.g. clean air and water, food, timber, recreation opportunities, biodiversity etc.) that people appreciate. Most of these services, though, are 'invisible' in the sense that they are often overlooked by decision-makers. While there is some ecological knowledge available about the flows of ecosystem goods and services provided by the Natural Capital, evidence is only partial. Furthermore, the monetary value of such ecosystem goods and services is often unknown, due to the fact that only a small part of the goods and services provided by nature are exchanged in formal market settings. One way to make the costs of environmental degradation and the benefits of environmental protection visible is through the development of Natural Capital Accounts. Natural Capital Accounts record changes in the extent and condition of natural assets over time, measure the resulting variation in the flow of ecosystem goods and services provided and, through economic valuation techniques, allow the quantification (in monetary terms) of such changes in service flows.

Reflecting international efforts, since 2011, the UK Government has been working with the Office for National Statistics (ONS) and Defra to produce Natural Capital Accounts for the UK. So far, experimental accounts have been produced for land use and forestry, freshwater assets and services, and scoping studies have been undertaken for peatlands, woodlands, and marine ecosystems, amongst others.[1] Most of the efforts to date have been focused on *national* accounts (accounts which consider the entire country's Natural Capital). However, focus has recently shifted to also include other spatial and organisational scales, with for example the Natural Capital Protocol initiative promoting the adoption of natural capital approaches at the level of individual businesses. Furthermore, the Natural Capital Committee has emphasised the need for more efforts to develop natural capital accounting also *at local and/or organisational* scale. These are accounts which consider smaller spatial extents and, for instance, are developed at the level of those organisations, businesses, NGOs or governmental departments who own and/or manage land on a local or regional scale. This can include for example parks, farms, nature reserves and

[1] For an overview of the Office for National Statistics and Department for Environment, Food, and Rural Affairs natural capital project and related publication, the interested reader should refer to:
https://www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/methodologies/naturalcapital

National Parks. Please note that such local or organisational Natural Capital accounts conducted at sub-national spatial scale can also include accounts for organisations which operate at a national level (e.g. RSBP), but own or manage various smaller extents of land across the country. This recent shift in focus from national to local, has in part come about through the recognition that much of our Natural Capital is owned or managed by both private and public organisations operating at smaller geographical scales. The role of such businesses and organisations is therefore crucial for the preservation of our natural environment and for the delivery of ecosystem goods and services. This is particularly true in the case of protected landscapes (e.g. National Parks).

It has been argued that Natural Capital accounting at local and/or organisational level can fulfil many purposes. As outlined by Eftec (Eftec 2015)[2] in a report on corporate natural capital accounting prepared for the Natural Capital Committee, the aim of developing natural capital accounts is to "*document an organisation's ownership, liability and assets related to natural capital in a balance sheet format. In the same way that the structured recording of other company assets and liabilities in conventional financial accounts informs and improves an organisation's management decisions, natural capital accounts will enable better decisions to be made about natural capital*". More specifically, as outlined in the Defra report on ecosystem accounts for protected areas in England and Scotland (2015), natural capital accounting can be helpful to guide organisations about resource management decisions, such as balancing competing priorities and identifying opportunities to enhance ecosystem functioning to maximise the delivery of ecosystem services. In addition, natural capital accounting can be used to promote awareness about the importance of natural capital and the interdependencies between the environment and people. By offering a consistent way to monitor and assess change in natural capital over time, natural capital accounts can also help organizations to identify trade-offs between different land uses and/or ecosystem services. Finally, natural capital accounts are helpful in creating clear messages and evidence to influence policy and funding decisions with environmental consequences.

Whilst being increasingly encouraged to produce natural capital accounts, many National Park Authorities, Area of Outstanding Natural Beauty (AONB) partnerships and other organisations often struggle with the task. Although increasingly aware of the extent and value of the ecosystem services provided, these organisations frequently lack the data, expertise and/or resources to comprehensively monitor all the natural capital within their protected landscapes, identify the related ecosystem goods and services, and quantify the wider benefits in economic terms, thereby making the development of natural capital accounts challenging. Several organisations have attempted the development of natural capital accounts at a local and/or organisational scale (see section 2.3). In the absence of any clear methodological guidance and in-house expertise, applications have mostly relied on adaptations of existing methods, primarily developed for

[2] Eftec (2015). Developing Corporate Natural Capital Accounts. Final Report for the Natural Capital Committee. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/516968/ncc-research-cnca-final-report.pdf

Natural Capital accounting exercises at international and national scale. These existing methods include approaches outlined in the System of Environmental-Economic Accounting (SEEA) Central Framework and the SEEA Experimental Ecosystem Accounting (SEEA EEA), developed by the United Nations and adapted for the UK by the ONS. In the present document we refer to the local-scale adaptations of such approaches as the "standard practice" in Natural Capital Accounts at organisational scale. Despite the growing number of local scale applications, though, little work has been done to understand the extent to which such international and national approaches are appropriate at a local or organisational scale. One concern is that large-scale approaches, such as those used for national accounts, may not be appropriate at a smaller scale, due to local variation in the delivery of ecosystem services. For example, whilst approaches using national data on agricultural production may be appropriate for the development of accounts at a national scale, agricultural production may be vastly different from the average for smaller areas of interest. The development of a methodology that is suitable for natural capital accounting at organisation level has been outlined as a priority by the Natural Capital Committee in its latest report published in January 2019 (Natural Capital Committee 2019)[3].

National Park Authorities have been specifically encouraged to develop Natural Capital Accounts. For example, the 2019 independent Landscape Review led by Julian Glover[4] advocated for the usefulness of Natural Capital Accounting for National Parks and AONBs. Similarly, in its 2018 annual report, the Natural Capital committee stated that "*England's Nationals Parks contain very significant natural capital, and their powers and duties should be extended to support the objectives of the 25 Year Environment Plan. Where practical, each National Park should quantify and value the main natural capital assets in its area*". For the specific case of National Park Authorities, developing Natural Capital Accounting is related to multiple challenges. Whilst National Park Authorities are encouraged to develop Natural Capital Accounts for the assets in their area, not all land within the National Park area is under ownership or management of the National Park Authority. This can lead to limitations in both the production (e.g. data availability) and usefulness (potential for influencing change) of Natural Capital Accounts produced for the entire National Park area.

In this report we review recent efforts and UK scoping and pilot case studies of natural capital accounts developed for organisations in the environmental sector. This project, part of the NERC-funded programme SWEEP (South West Partnership for Environmental and Economic Prosperity), focuses on critically assessing the advantages and disadvantages (potential limitations) for decision-making of using 'standard approaches' to natural capital accounting at a local or organisational scale. It also discusses possible options to overcome the identified challenges, in order to make the natural capital approach more useful to inform decision-making. For this project, we focused on Dartmoor and Exmoor National Parks as our case study areas and

---

[3] Natural Capital Committee (2019). State of Natural Capital Annual Report 2019. Sixth report to the Economic Affairs Committee of the Cabinet. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/774218/ncc-annual-report-2019.pdf

[4] Landscapes review: National Parks and AONBs (2019). Available at: https://www.gov.uk/government/publications/designated-landscapes-national-parks-and-aonbs-2018-review

considered the entire geographical area within the National Park boundaries. The whole National Park area was selected because, as mentioned earlier, the Natural Capital Committee recommended that "*each National Park should quantify and value the main natural capital assets in its area*"; we therefore interpreted this as a recommendation to consider the entire area of interest which falls under the organisation's remit, i.e. the whole National Park, rather than exclusively the land owned or managed by the National Park Authorities.

2 NATURAL CAPITAL ACCOUNTS IN THEORY

2.1 THE NATURAL CAPITAL APPROACH

The framework underlying Natural Capital Accounting is based on the Natural Capital approach. The natural capital approach is a way of thinking about nature as a production system that provides humans with flows of valuable goods and services. The Natural Capital Approach can be viewed as a 4-step framework, as outlined in Figure 1.

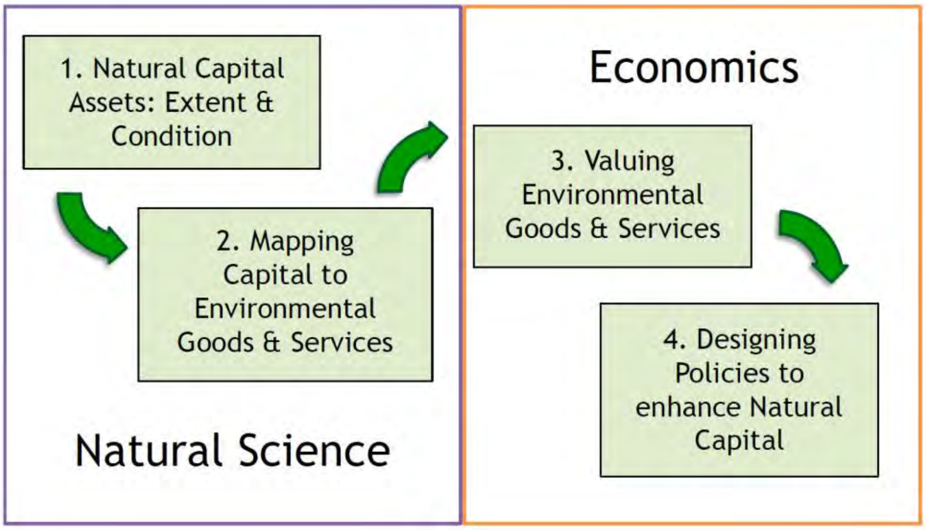


Figure 1. The steps of the Natural Capital approach

The first step in the natural capital approach involves establishing the extent and condition of natural capital assets or stocks - "the naturally occurring living and non-living components of the Earth, together constituting the biophysical environment, which may provide benefits to humanity" (ONS 2017)[5]. For example, a woodland is a natural capital stock.

The second step focuses on mapping the environmental pathways through which changes in natural capital result in changes in the flow of ecosystem goods and services that are valued by people. For example, soil, water and seeds contribute, through complex biophysical or natural processes such as water and nutrient cycles, to the growth of forests, which then provide a wide array of environmental goods and services, such as trees and carbon sequestration. Whilst some of these environmental goods and services are appreciated in their own right (e.g. the wonder

[5] ONS (2017). Principles of Natural Capital Accounting. A background paper for those wanting to understand the concepts and methodology underlying the UK Natural Capital accounts being developed by ONS and Defra. Available at: https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/principlesofnaturalcapitalaccounting

inspired by nature), their major value to humans is derived when the environmental goods and services are used in combination with a range of human, social, manufactured and other capital that are part of the economic production system. This yields a plethora of highly valuable goods and services which are crucial to human wellbeing, including stable supplies of food and water, materials and defence from hazards. There are different ways through which a given environmental good or service can generate benefits to people. For instance, trees are an environmental good and they are used to produce timber, using labour input from a forester. Timber is then crafted by a carpenter, using tools to produce furniture, which is then sold on to consumers, who gain welfare from using it. However, there are other possible channels through which individuals may benefit from trees. Trees can enhance the views that people enjoy from their homes and the vicinity to forested areas contributes to improve residents' quality of life.

The next step in the natural capital framework is to establish the economic value of the flows of the identified ecosystem goods and services (step 3). Whilst the flows of goods and services can be assessed through a wide variety of units and metrics (e.g. tonnes of CO_2 sequestered by trees, or numbers of game animals), translating these metrics into something that conveys information about the impacts on human wellbeing is more challenging. By far the most common approach is to apply methods developed by economists to determine the economic values provided by the environment (expressed in monetary terms). For some environmental goods and services (e.g. timber or crop production), information on the value conveyed to individuals is readily available through market prices (which reflect the *private benefits* or value of the good to the buyer). However, for most ecosystem goods and services (e.g. clean air or good water quality) information is not directly available on the value provided to people. These goods and services are not traded in markets, even though they provide benefits that are enjoyed by many individuals (so called *public benefits*). Methods are available to estimate the economic value of changes in the flow of these non-market goods and services.

The last step in the Natural Capital approach consists of using the information about the benefits and values of ecosystem goods and services to inform decision-making, e.g. to design policies and management practices to enhance natural capital (step 4).

2.2 PRODUCING NATURAL CAPITAL ACCOUNTS – THE THEORY

As mentioned in the introduction, Natural Capital Accounts can be produced by following the guidelines developed internationally, e.g. the System of Environmental-Economic Accounting (SEEA) Central Framework and the SEEA Experimental Ecosystem Accounting (SEEA EEA) by the United Nations. At UK level, these guidelines are adopted and adapted by the Office for National Statistics (ONS) and the Department for Environment, Food and Rural Affairs (Defra). In this section, we outline the main concepts and methodologies to produce Natural Capital Accounts in the UK, mostly drawing on the guidelines presented by the ONS in their background paper on the 'Principles of Natural Capital Accounting' (ONS 2017)[6]. The principles and approaches outlined have been developed for national scale accounts. No specific guidelines have yet been issued for more spatially disaggregated accounts, although some methodological guidance is provided in the Natural Capital Committee's Sixth Report (Natural Capital Committee 2019)[7], which is consistent with the recommendations outlined by the ONS (ONS 2017)[8] and in this report.

Natural Capital Accounting was first developed as an expansion of the System of National Accounts (SNA) to provide a more complete picture of the economic wealth of a nation. SNAs rely on the Gross Domestic Product (GDP) to measure value; these focus only on the flows of income and outputs, therefore omitting consideration of the services provided by natural capital. Hence, Natural Capital accounting is a useful (and necessary) addition, as it helps incorporate the value generated by the environment to people into the measurement of welfare/wellbeing.

Natural capital accounting relies on a series of interconnected accounts that provide a structured set of information on natural capital stocks, services and values. Natural capital accounts capture changes in the stock of natural capital, the flows of ecosystem services supplied by them and their value. They are structured in a way that consistently reflects the principles employed in the SNA to make comparison possible. However, a Natural Capital account can consist of a selection or combination of different types of accounts, each emphasising a specific steps (or linking different steps) identified in the Natural Capital framework described in section 2.1. One first distinction is between physical accounts – measuring the extent and condition of the assets and the resulting amount of goods and services produced annually – and monetary accounts – providing information on the monetary valuation of selected services or of a natural asset (see Figure 2). Another important distinction is between asset accounts – focusing on the state of the assets (i.e. volume or extent and its condition or quality) – and service accounts – recording information on the service flows provided by natural assets over a certain time period (typically one year). Both stock (asset) accounts and flow (services) accounts can be in either monetary or physical terms, and can be produced for one or multiple years, to capture how stocks and the provision of services have changed over time.

[6] ONS (2017). Principles of Natural Capital Accounting. A background paper for those wanting to understand the concepts and methodology underlying the UK Natural Capital accounts being developed by ONS and Defra. Available at: https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/principlesofnaturalcapitalaccounting

[7] Natural Capital Committee (2019). State of Natural Capital Annual Report 2019. Sixth report to the Economic Affairs Committee of the Cabinet. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/774218/ncc-annual-report-2019.pdf

[8] ONS (2017). Principles of Natural Capital Accounting. A background paper for those wanting to understand the concepts and methodology underlying the UK Natural Capital accounts being developed by ONS and Defra. Available at: https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/principlesofnaturalcapitalaccounting

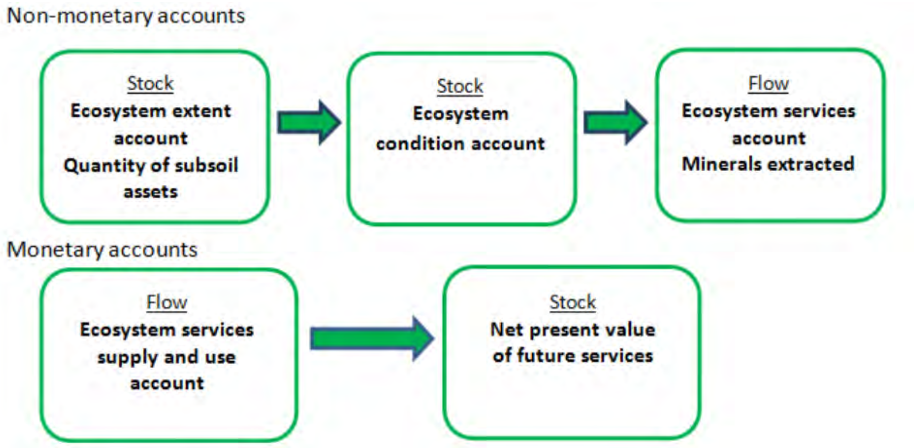


Figure 2. The possible types of Natural Capital accounts (adapted from ONS (2017)[9])

2.2.1 Non-monetary stock accounts

These accounts capture information on the extent and condition of different natural capital stocks within a pre-defined area (e.g. a nation, a region or a park). Typically, the starting point consists of the categorisation of natural capital stocks into land cover classes. In the UK, the ONS and Defra recommend using the Land Cover Map (LCM) data, first released by the Centre for Ecology and Hydrology (CEH) in 1990 and subsequently for the years 2000, 2007 and 2015. These data are deemed to be the best available source of natural capital asset data in the UK for the purposes of natural capital accounting because they are spatially comprehensive and offer information on stock extent over repeated years, although the way in which data are collected varies slightly across years. Inconsistency in methodology can, as we will discuss later, reduce the reliability of stock change detection over time.

In addition to collecting information on the change in asset extent over time, information on the condition or quality of the natural capital stocks is also highly informative. The ONS recommends considering a broad set of condition indicators, including for example volume estimates (e.g. timber biomass.), soil indicators (e.g. carbon or water content), ecological condition (e.g. water quality, level of land degradation) and spatial configuration (fragmentation or connectivity). The condition of ecosystem assets is an important element driving the capacity of natural capital to deliver ecosystem services. Whilst it is acknowledged that information on natural capital stock condition is not always available, it is recommended that when this information is available, it should be reported.

Once the asset accounts are completed, information on stock extent and condition can, if useful, be linked with information on land use, landscape type, land ownership, protected area status

[9] ONS (2017). Principles of Natural Capital Accounting. A background paper for those wanting to understand the concepts and methodology underlying the UK Natural Capital accounts being developed by ONS and Defra. Available at: https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/principlesofnaturalcapitalaccounting

and land management practices to have a richer understanding of the drivers of change. An example of an asset account, incorporating extent and condition information on the different stocks, is reported in Appendix 1.

2.2.2 Non-monetary ecosystem service flow accounts

After producing asset accounts, flow accounts are built to record information on the flow of ecosystem goods and services provided by the stock of natural capital and appreciated and valued by people.

The ONS and Defra refer to the Common International Classification of Ecosystem Services (CICES) as one possible standard to be followed in the classification of the ecosystem goods and services in the accounts. This classification system reflects the well-established distinction between provisioning, regulating and cultural services. Provisioning services refer to all those goods and services that can be directly consumed by people (e.g. food, drinking water) or used as inputs in productive activities (e.g. energy, timber). Regulating services are those resulting from well-functioning ecosystem processes (e.g. climate regulation, flood regulation, pollination, etc.). Cultural services are the non-material benefits that people obtain from the enjoyment of ecosystems (e.g. recreation, education).[10] A recommended checklist of ecosystem goods and services suggested by the ONS-Defra for use in Natural capital accounts is reported in Appendix 2.

2.2.3 Monetary accounts

In natural capital accounting, information on both the stock of natural assets and the associated flow of ecosystem goods and services can be reported in both physical and monetary terms. Monetary valuation allows environmental stocks and flows to be integrated and compared with the SNAs using a common metric (money) as a measure of value. The value of stocks is usually calculated as the aggregate value of the flow of ecosystem goods and services that are expected to be produced by the natural capital over a period of time into the future, until the end of the asset life (i.e. when the ecosystem asset is no longer able to supply the ecosystem service in question). This accounting asset life depends on the characteristics of the asset, but also on the management of the asset and the sustainability in the use of natural resources. In the UK Natural Capital monetary estimates published in 2016, the ONS (2017) has considered an asset life of 50 years for all renewable resources, hence adopting a simplified approach. To calculate the aggregate value of the asset over the full asset life, the net present value approach is usually considered. This assumes that the aggregate value of an asset is not simply calculated as the sum of the annual values, but rather as the sum of the discounted flows of values over time. To do so,

[10] http://uknea.unep-wcmc.org/EcosystemAssessmentConcepts/EcosystemServices/tabid/103/Default.aspx

a discount rate is applied. This reflects the weight that people assign to goods and services provided in the future. Discount rates tend to assign a lower value to goods and services being delivered later in time, given that people prefer to enjoy them sooner rather than later. The HM Treasury Green Book currently recommends the use of a Social Discount Rate of 3.5% for flows of services supplied up to 30 years into the future, and 3.0% for 31 to 75 years, although there is ongoing discussion regarding the most appropriate discount rates to apply to environmental goods and services.

In many cases, information on the value of ecosystem goods and services provided by nature is not readily available. For some goods and services (e.g. timber or crops) the market price reveals the value of the good to buyers. However, in most circumstances, environmental goods and services (e.g. clean air, healthy biodiversity, functioning habitats, etc.) do not have a market price, as they are not traded in markets. For these goods, information on the value needs to be inferred using different approaches. To estimate values that are compatible with the SNA, valuation approaches for non-market environmental goods should, where possible, focus on *exchange values*. An exchange value is the monetary amount that would have resulted from a feasible transaction between a supplier and a beneficiary, "if a market existed". Where exchange values cannot be satisfactorily identified, alternative *welfare values* can also be considered, based on an individual's "willingness to pay" for a good or service – this is usually greater than exchange values. To estimate the value of the flow of environmental goods and services, a range of established valuation techniques can be used:

- Market-based methods, including:
    - The market price approach, which relies on the consideration of prices for given marketed ecosystem services (e.g. standing timber, crops, etc.). This approach is consistent with the principles of exchange values.
    - The resource rent approach, which measures the surplus value to the extractor or user of a natural capital asset after all costs and normal returns have been taken into account. Resource rent approaches are particularly suitable to value provisioning services (e.g. drinking water abstraction).
    - The production function approach, which values the importance of ecosystem services (typically regulating services) by studying their contribution to market-based production processes that have a market value. An example of this approach is the role of pollinators in crop pollination. It could be argued that the value of pollinators corresponds to the agricultural profit that would be lost in the absence of insects.

- Revealed preference methods, including:
    - The hedonic pricing method, which focuses on estimating the contribution of environmental services to market-based transactions, typically in the framework

of the housing or the labour markets, where environmental quality is a characteristic of properties or jobs. For example, we can think about the role of sceneries or nice views on residential property prices.

    - Averting behaviour approaches estimate the value of environmental changes through the price that people have to pay for given substitute products that become needed, following a drop in environmental quality or quantity. For instance, the value of clean drinking water can be estimated based on the amount of money that people are willing to spend on bottled water in situations when drinking water is contaminated or of reduced quality.
    - The travel cost method, which measures people's willingness to pay (usually recreational values) is based on information on the visited sites and the costs (in terms of travel costs and time) that individuals are willing to incur to access a given location with given environmental characteristics. The value that people get from visiting a given site generally exceeds the actual access or travel cost incurred and, therefore, the estimated willingness to pay corresponds to a measure of welfare, rather than simply exchange, value.

- Cost-based methods, including:
    - The damage costs avoided method, which estimates the value of a given environmental service (most typically regulating services) by calculating the cost savings incurred because of the existence of the ecosystem service of interest. For example, the value of air pollutant absorption services by trees can be calculated as the health treatment costs not incurred by the NHS as a result of lower health risks attributable to the presence of vegetation.
    - Replacement cost approach, which estimates the value of an environmental service by calculating the investment costs that would be incurred if the ecosystem service under consideration didn't exist or was lost. For example, the flood defence value of coastal margins can be estimated by calculating the costs of flood defence structures in areas which are similar but have no natural flood defences.

- Stated preference methods, including contingent valuation and discrete choice experiments, estimate the value of environmental goods by asking respondents to express their preferences in a survey setting, usually presenting hypothetical environmental scenarios of change. Stated preference methods provide welfare rather than exchange values, but their use is accepted for natural capital accounting purposes when no alternative methods are available.

A summary of the available valuation methods and recommendations regarding the most appropriate approach to use for valuing the different ecosystem services in natural capital accounting, is provided in Appendix 3.

2.3 PRODUCING LOCAL NATURAL CAPITAL ACCOUNTS - IN PRACTICE

Responding to the increasing calls for more efforts to develop natural capital accounts at organisational scale, a wide range of organisations, including those with an environmental and/or conservation focus, have recently started to either produce or commission their own natural capital accounts. For example, the RSPB has produced a Natural Capital Account for the estates that the organization owns and/or manages (RSPB 2017)[11]. Other examples include the work by DEFRA, AECOM and other partners, which have produced Natural Capital Accounts for Protected Areas in England and Scotland.

Overall, whilst alternative approaches and methods are considered by the different organisations for the measurement of natural capital stocks, ecosystem services and valuation, there are also substantial commonalities in the approaches and methods adopted. In this report, we refer to these as the current "standard practice" in natural capital accounting for environmental organizations. "Standard practice" approaches often rely on the use of simplified methodologies and generally use readily available data on natural assets (e.g. land cover maps) and on ecosystem services (e.g. literature on carbon storage by habitat type). Once goods and services are quantified, this information is generally multiplied by per unit values (based on a range of valuation approaches) to compute the total economic value. The "standard practice" approaches frequently adopted are reviewed in more detail in section 3 and Appendices 5 and 6.

Past Natural Capital Accounts at organisational scale have revealed that the "standard practice" approach, based on the multiplication between Price and Quantity, has some clear strengths. It is a useful method for incorporating "Natural Capital thinking" into an organisation's philosophy, and can provide an overview of the interdependencies between the natural world, organisations and society. Using readily available data simplifies the process for the organisation and minimises the resources involved in producing a Natural Capital Account. However, there are also some key limitations and difficulties that need to be considered. A "one size fits all approach" is not appropriate as there are differences in assets and ecosystem services provided by different areas of interest. Hence, generalisations, as used in "standard practice" approaches, are not suitable in many circumstances. In addition, readily available datasets on assets often do not match the level of detail needed to inform management decisions. It is therefore important to ensure a good balance between the ease of simplified approaches and the more in-depth analysis required for comprehensive and informative accounts to guide decision-making.

Given these limitations, there is a concern that currently available approaches to produce Natural Capital accounts at an organisational level may not give the desired information to guide

[11] RSPB (2017). Accounting for Nature: A Natural Capital Account of the RSPB's estate in England

management decisions. In this project, we review "standard practice" approaches, replicate them by developing Natural Capital Accounts for Dartmoor and Exmoor National Parks and evaluate the usefulness of such approaches to inform land management decisions. We also test the sensitivity of the accounts to the use of different data sources and methodologies, and explore potential ways in which organisations can incorporate additional data and expertise into the standard approach to improve the overall accuracy and usefulness of the accounts.

3 METHODOLOGY

The focus of this project is to critically assess the advantages and limitations of applying the current "standard practice" approach to develop accounts at regional or organisational scale. With "standard practice" in this report we mean those efforts which have sought to adapt international and national Natural Capital accounting methodologies and principles to a regional or organisational scale. Dartmoor and Exmoor National Parks are used as case studies for our critical assessment. Our methodology to produce the accounts was based on a review of published natural capital accounting scoping studies/reports and of ecological and environmental economics literature, supported by consultations with management and technical staff from both National Parks. Figure 3 summarises the steps taken in the project.

After identifying Dartmoor and Exmoor National Park Authority's aspirations regarding the use of natural capital accounts to inform their decision-making, we reviewed the approaches adopted by different (scoping) studies, and replicated these for the two National Parks. We next tested the sensitivity of the account results to alternative estimates (obtained from the academic literature or alternative datasets), based on different 'assumptions' regarding the natural assets, flows of ecosystem services and goods and values, and discussed the implications. We concluded this study by critically discussing the usefulness of natural capital accounts for management decisions, by referring to the discussions and consultations with stakeholders at the various stages of the project.

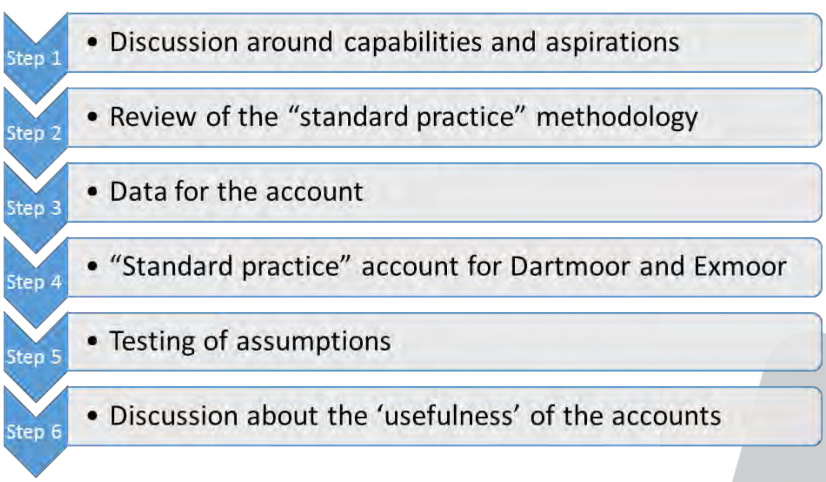


Figure 3. Steps in the production of "standard practice" Natural Capital Accounts for Dartmoor and Exmoor National Parks

3.1 STEP 1: CAPABILITIES AND ASPIRATIONS.

The first step in this project was to establish the National Park Authorities' aspirations as to how a Natural Capital account might inform their decisions. The aim of this step was to set a baseline against which to assess, at the end of the project, whether the produced accounts have met the initial aspirations. In a workshop setting, we held a structured discussion with key staff members from both National Park Authorities (management and ecologists) to identify their expectations regarding what a Natural Capital Account could be useful for within their organisation. The discussion was firstly based on a list of items summarising possible ways in which natural capital accounts can be useful to inform decision-making (based on the Defra report on NCA in protected areas)[12]:

- promote understanding and awareness
- influence policy decisions and secure funding
- support decision-making and management
- identify opportunities to enhance the ecosystem functionality
- explore innovative mechanisms for revenue generation

In addition to presenting these general points, we also displayed a list of specific management ambitions (taken from Dartmoor and Exmoor National Park Authorities' Management Plans[13]) to discuss whether it was felt that Natural Capital Accounting could be a useful tool to provide answers to specific management questions. Based on the discussions with stakeholders, we compiled a list of aspirations regarding how each National Park Authority was hoping to use Natural Capital Accounts to inform decisions.

Exmoor National Park Authority's aspirations:

- Demonstrate how the natural capital approach can be used in the context of the "National Park" designation
- Understand how the Natural Capital approach can be used for post-Brexit farm and environmental support (Exmoor's ambition)[14]
- Guide land management, investment and protection
- Use as a tool to inform:
    - Mires rewetting

[12] White, C., Dunscombe, R., Dvarskas, A., Eves, C., Finisdore, J., Kieboom, E., Maclean, I., Obst, C., Rowcroft, P. & Silcock, P. (2015), 'Developing ecosystem accounts for protected areas in England and Scotland', Department for Food, Environment & Rural Affairs/The Scottish Government.

[13] Available at: www.yourdartmoor.org.uk and https://www.exmoor-nationalpark.gov.uk/about-us/key-documents.

[14] Report on Exmoor National Park's ambition, a transformative proposal for sustaining and enhancing Exmoor's farmed landscapes and communities after Brexit, is available from: https://www.exmoor-nationalpark.gov.uk/__data/assets/pdf_file/0010/1112869/ExmoorsAmbition_Web.pdf

    - Grassland restoration
    - Sustainable construction
    - Winter grazing
    - Land holdings

Dartmoor National Park Authority's aspirations:

- Incorporation of Natural Capital Accounts in the State of the Park Report and Management plan
- Update Natural Capital Accounts on a 5-year basis to see how the stocks/flows/values changed over that period
- Use this to inform which priorities/actions/management changes should be considered in the next management plan review
- Look at how information from accounts may inform future environmental land management schemes
- Use as a tool for informing:
    - The state of air quality
    - Orchard losses
    - Farming Futures
    - Links with management of the Duchy estate
    - Recreation management

Common management ambitions to both Dartmoor and Exmoor National Park Authorities include:

- Woodland management
- Natural Flood Management
- Invasive species control
- Swaling
- Scheduled Monument management

Based on the compiled lists and wider discussions, the following were identified as priority ambitions regarding the potential uses of Natural Capital Accounts:

Exmoor National Park Authority	Dartmoor National Park Authority
• Provide an improved framework for the State of the Park report	• Improved framework for the State of the Park report
• Informing Environmental Land Management Schemes (ELMS)/payment for farming, e.g. by putting value on provided ecosystem services	• Explore the use of Natural Capital accounting for investment decision-making, e.g. when needing to prioritise between two management/restoration options.
• Land ownership/land holdings: understand the best use of land owned by the Exmoor National Park Authority	• Leveraging funding/justifying spending. Understanding the monetary value of e.g. a restoration project, and use this knowledge to leverage funds to cover project costs
• Use to illustrate gaps in decision-making	• Influencing management decision-making, e.g. increasing the size of high value stocks

Despite some aspirations being specific to the context of the Dartmoor and Exmoor National Park Authorities, the identified ambitions generally reflect wider national expectations (summarized earlier in this report) regarding how natural capital accounting is believed to help informing decision-making in environmental organisations.

3.2 STEP 2: REVIEW OF EXISTING “STANDARD PRACTICE"

After discussing the National Park Authorities’ aspirations regarding the use of Natural Capital Accounts, the team focused on reviewing the relevant scoping studies and reports to compile information on the “standard practice” for Natural Capital accounting at an organisational scale. The aim of this step of the work was to review the methodology, datasets and quantitative estimates used by existing scoping studies and reports on Natural Capital accounting, to be able to replicate the “standard practice” in our case study areas. We reviewed a sample of Natural Capital Accounts produced at a local or organisational scale by UK organisations with an environmental remit. Given the limited availability of relevant examples of approaches for selected ecosystem services, we also considered some national case studies to improve accounts’ completeness – mostly focusing on the ONS scoping studies.

The following list of reports was reviewed:

- White, C., Dunscombe, R., Dvarskas, A., Eves, C., Finisdore, J., Kieboom, E., Maclean, I., Obst, C., Rowcroft, P. & Silcock, P. (2015), '**Developing ecosystem accounts for protected areas in England and Scotland'**, Department for Food, Environment & Rural Affairs/The Scottish Government
- RSPB (2017). **Accounting for Nature: A Natural Capital Account of the RSPB's estate in England**
- Rouquette, J.R. (2016). **Mapping Natural Capital and Ecosystem Services in the Nene Valley.** Report for the Nene Valley NIA Project.
- Cryle, P., Krisht, S., Tinch, R., Provins, A., Dickie, I., Fairhead, A. (2015**). Developing UK natural capital accounts: woodland ecosystem accounts.** Economics for the Environment Consultancy Ltd (Eftec) in association with Cascade Consulting for the Department for Environment, Food and Rural Affairs (Defra)
- Office for National Statistics scoping studies:
  - Jones, L., Vieno, M., Morton, D., Cryle, P., Holland, M., Carnell, E., Nemitz, E., Hall, J., Beck, R., Reis, S., Pritchard, N., Hayes, F., Mills, G., Koshy, A., Dickie, I. (2017). **Developing Estimates for the Valuation of Air Pollution Removal in Ecosystem Accounts.** Final report for Office of National Statistics, July 2017
  - Richard Smithers, Outi Korkeala, Guy Whiteley, Shaun Brace, Bex Holmes (2016). **Valuing flood-regulation services for inclusion in the UK ecosystem accounts.** Ricardo Energy & Environment for the UK Office for National Statistics
  - Office for National Statistics (ONS) (2016) **Scoping the UK coastal margin ecosystem accounts**

A range of other reports[15] (including Exmoor's "Towards a Register of Exmoor's Natural Capital") were included in the review, but could not be used for the purposes of this project because they either provided only qualitative information, or they provided quantitative figures which were though not readily transferrable to Dartmoor and Exmoor National Parks.

In order to replicate the "standard practice" approach, information had to be derived on: 1) the natural capital stocks and underpinning datasets for stock quantification, 2) the considered

[15] List of reports reviewed but not providing quantitative and easily transferrable information to build standard practice NCAs:
- Deane R and Walker A (2018). Towards a Register of Exmoor's Natural Capital. Report to the Exmoor Society, Dulverton
- Hölzinger, O., Laughlin, P. (2016). Cornwall Area of Outstanding Natural Beauty (AONB) Natural Capital Assessment
- Whiteley, G., Shabb, K., Korkeala, O., Mccullough, A., Smithers, R. (2016). Reviewing cultural services valuation methodology for inclusion in aggregate UK natural capital estimatesReport for Office National Statistics
- Office for National Statistics (ONS) (2017). UK natural capital: developing UK mountain, moorland and heathland ecosystem accounts.
- Dickie I., Evans C., Smyth M.A., Artz, R. (2015). Scoping the Natural Capital Accounts for Peatland, work package 3 of Report NR0165 for Defra.
- Office for National Statistics (ONS) (2018). UK natural capital: developing semi-natural grassland ecosystem accounts.
- Office for National Statistics (2018). UK Natural Capital: Ecosystem service accounts 1997 to 2015
- Office for National Statistics (2016). UK Natural Capital: Monetary estimates 2016

ecosystem goods and service flows, and the data used to quantify these flows and 3) the valuation methodology and values used.

Based on the reviewed reports, we compiled a list of natural capital stocks generally considered in the reviewed Natural Capital accounting approaches. In most of cases, the asset classes considered match with those generally used in publicly available land mapping datasets. Following discussions with the National Park Authorieties, and given the fact that in-house mapping was often dated or did not cover the full extent of the National Park area, it was decided that the project would follow the ONS recommendations and use the CEH Land Cover Map 2015 asset categories and data. This was viewed as the best option, given that it ensures a comprehensive coverage across both National Parks. In addition, using the CEH Land Cover Map data, whose collection is periodically repeated at national scale, allows to potentially replicate Natural Capital accounting exercises for Dartmoor and Exmoor in the future. This approach is also in line with the one used, for example, in the DEFRA report for Protected Areas and in the ONS scoping study focusing on coastal margins, both relying on the 2007 Land Cover map data.

For Dartmoor National Park, park-wide local data on Rhos pasture and Dry Grassland was available. Given the relevance of these habitat classes in Dartmoor, the LCM classification and resulting habitat extent calculations were adapted to incorporate data on Rhos pasture and Dry Grassland. The final list of considered assets for both Dartmoor and Exmoor is included in Appendix 4.

Based on the "standard practice" approaches reflecting the ONS recommendations, reviewed reports and discussions with the National Park Authorities, we then compiled a list of ecosystem goods and services of interest to be included in the National Parks' Natural Capital Accounts. The following ecosystem goods and services are considered in this project:

- Recreation
- Wild food (game)
- Climate regulation (greenhouse gas sequestration)
- Timber
- Crops
- Drinking water
- Air quality regulation
- Minerals
- Biodiversity
- Pollination
- Flood protection
- Livestock
- Plants and seed
- Volunteering

For comparison purposes, we also provide a list (Table 1) of the ecosystem goods and services that were considered (but not always quantified) in the reviewed reports mentioned earlier in this section. The majority of these ecosystem goods and services are in line with the recommendations set out by the ONS (ONS 2017). However, there are also some additional goods and services, including energy production (e.g. hydropower, wind) and waste remediation, that are considered by some reviewed studies but are not frequently included in Natural Capital Accounts. Please, note that we discuss the difficulty of valuing cultural services other than recreation (such as aesthetic value and archaeological heritage) later in this report.

Table 1. The ecosystem goods and services considered in this project and other Natural Capital Accounting projects for organisations with an environmental remit.

Dartmoor & Exmoor	D	R	N	E	Coastal margins
Recreation	+	+	+	+	+
Wild food	+				
Climate regulation	+	+	+	+	+
Timber	+			+	
Crops	+	+	+		
Drinking water	+	*	*		
Air quality regulation	+	*	*		+
Minerals					
Biodiversity					
Pollination			+		
Flood protection	*		*	+	+
Livestock	+				
Plants & seeds					
Volunteering		+			
	Other water uses				
	Energy (woodfuel)	* (biomass briquettes)			
	Education*	+			
	Heritage*				
	Aesthetic	*			
	Existence*				
		Conservation*			
			Agricultural emissions		
			Noise regulation*		
			Tranquillity*		
			Accessible nature*		
			Green travel*		

Note: A plus symbol (+) indicates the services which were considered in the reviewed reports, an asterisk (*) indicates services that were considered, but were not successfully quantified or estimated. Notes: **D = Defra NCA**

for protected areas (Ref: White, C., Dunscombe, R., Dvarskas, A., Eves, C., Finisdore, J., Kieboom, E., Maclean, I., Obst, C., Rowcroft, P. & Silcock, P. (2015), 'Developing ecosystem accounts for protected areas in England and Scotland', Department for Food, Environment & Rural Affairs/The Scottish Government); **R=accounts for RSPB estate** (Ref: RSPB (2017). Accounting for Nature: A Natural Capital Account of the RSPB's estate in England); **N = Nene Valley report** (Ref: Rouquette, J.R. (2016). Mapping Natural Capital and Ecosystem Services in the Nene Valley. Report for the Nene Valley NIA Project); **E = Eftec woodland NCA for the UK** (Ref: Cryle, P., Krisht, S., Tinch, R., Provins, A., Dickie, I., Fairhead, A. (2015). Developing UK natural capital accounts: woodland ecosystem accounts. Economics for the Environment Consultancy Ltd (Eftec) in association with Cascade Consulting for the Department for Environment, Food and Rural Affairs (Defra)); **O = ONS study valuing coastal areas** (Ref: Office for National Statistics (ONS) (2016) Scoping the UK coastal margin ecosystem accounts).

In addition to the type of ecosystem services provided by natural capital stocks, information also needs to be collated from the reviewed reports about the amount of ecosystem goods and services provided (for example, tonnes of Carbon sequestered per hectare of heather grassland, or tonnes of crops per hectare of agricultural land). Appendix 5 summarises the approaches adopted by the reviewed reports and then used in the preparation of the Natural Capital Accounts for the National Parks. Often, only one approach was available to quantify the ecosystem goods and services, but in several cases multiple options could be considered. In this latter case, the approach that we followed was based on the consideration of the most plausible and practical approach, based on scientific soundness (well-established evidence), local relevance (i.e. applicable to Dartmoor and Exmoor habitats), and feasibility (e.g. the underpinning data being publicly available). When there was uncertainty regarding which approach to use, National Park Authority staff was consulted in the selection process.

The following step in the process consisted of compiling information on the methods employed by the "standard practice" Natural Capital accounts to value (in monetized terms) the benefits provided by the ecosystem goods and services supplied by the natural assets. Generally, the reviewed Natural Capital accounts tended to employ the valuation approaches suggested by the ONS and, in turn, the SEEA (summarised in Section 2.2. of this report). Appendix 6 summarises the valuation approaches employed in our exercise for Dartmoor and Exmoor National Parks. When multiple options were available, expert judgement was used to select the most appropriate (scientifically sound) approach, and stakeholder consultations helped to assess the local relevance and applicability of the proposed method.

An Excel framework was developed to record the quantifications of the natural capital stocks, the ecosystem goods and services and the economic values. The spreadsheet consists of one tab for each ecosystem service. Each tab contains a separate table for each natural capital stock class and sub-class and is used to calculate the value of each ecosystem service provided by each stock type. An example of these tables can be found in Figure 4, which focuses on carbon sequestration services in coniferous woodlands.

		Unit of measurement:	Source of quantification:	Strengths:	Limitations:	Suggestions for improvements:	Any other comments:
Stock:	Coniferous woodland						
Stock extent (ha):	10						
1a. Amount of good produced (per ha):	12	tonnes of CO2e sequestered/ha/year					
1b. Amount of good produced (per ha):							
2a. Value per unit of good (£):	56	£/tonne of CO2e					
2b. Value per unit of good (£):							
Valuation (1a & 2a): (no. ha * amount of good produced/ha * value per unit of good)	10*12*56=£6720						
Valuation (1a & 2b):							
Valuation (1b & 2a):							
Valuation (1b & 2b):							

Figure 4. Example of the Excel table structure used to record information on the reviewed estimates of service flows and values for each stock

From top to bottom, each table records:

i) The stock extent, e.g. the extent of coniferous woodlands in the area under consideration (in blue)

ii) The amount of good or service produced per hectare, e.g. tonnes of carbon sequestered per hectare of coniferous woodland (in pink)

iii) The unit value of the ecosystem services, e.g. the value of carbon (in £) per tonne (in green)

iv) The total value of the ecosystem good or service for this stock (in orange), obtained by multiplying the number of hectares (i) by the amount of goods produced per hectare (ii) and the value per unit of the good (iii).

As reported in Figure 4, ten hectares of coniferous woodlands sequester 12 tonnes of carbon (CO_2 equivalent). Given that the value of a tonne of CO_2 equivalent sequestered is £56 (for 2011), it is easy to calculate the total value of the flow of carbon sequestration services provided by coniferous woodlands, as 10*12*56=£6,720 per year.[16] All calculations were conducted using Excel formulas so that workings could be traced.

In addition, in the white section of the table, we recorded information about the source documents and the unit of measurement used in the quantifications. Where available, we also included information on the strengths and limitations of each approach, suggestions for improvement, and any other relevant comments. In the spreadsheet, we considered one row for each of the reviewed reports and used different letters to be able to link the recorded information to the corresponding source document.

[16] If unit values were available for a different year compared to that considered in the accounts, the values were adjusted to the year of interest by using the GDP deflator formulas, which make it possible to account for the fact that prices changes over time due to inflation. Prices adjusted for the GDP deflator are reported on the left of each table in the Excel spreadsheet.

3.3 STEP 3: DATA FOR THE ACCOUNT

Starting from the list of selected natural capital stocks, ecosystem goods and services and values considered by “standard practice” Natural Capital Accounts, the team worked with the NPAs to assess the quantity and quality of data available to populate the accounts. Information on the extent of each selected natural capital stock (land cover type) was obtained, using ArcGIS, from the CEH Land Cover Map 2015 data. Additionally, for DNPA, data on Rhos pasture and Dry Grassland were also considered (see step 2 of the methodology and Appendix 4). In some cases, quantifications of the values and the flow of ecosystem goods and service provided by the natural capital stocks could be obtained directly from the reviewed reports (step 2). For example, information on the amount of carbon sequestration and air pollution capture per hectare for different habitat types was available directly in the reviewed reports. In other cases, extra calculations were required to quantify the ecosystem services and values for the specific case study area of interest. For example, for Recreation and Volunteering, the annual number of visitors and the number of volunteer hours needed to be obtained specifically for each of the National Parks. See Appendices 5 and 6 for details on the methodologies for valuation and the quantification of ecosystem goods and service flows.

3.4 STEP 4: “STANDARD PRACTICE" NATURAL CAPITAL ACCOUNT

Starting from the list of the most plausible quantifications obtained in Step 2 for selected natural capital stocks, flows of goods and services and values, and the data obtained in Step 3, we drafted a Natural Capital Account for Dartmoor and Exmoor National Parks. The account, reflecting “standard practice” approaches, was produced by combining the information from the individual Excel tables for each ecosystem service and stock into one large table, summarising the total ecosystem service provision and values for a given year. This summary Natural Capital Account table was created as a separate tab in the Excel spreadsheet and was populated by using formulas to ensure that any change introduced elsewhere in the spreadsheet (e.g. a change in a stock extent, a change in the amount of ecosystem service produced, or the value of that service) was automatically updated and reported in the summary table. This sets up a convenient framework for updating the accounts when changes in assets, services or values become available. See Figure 5 below for an example of part of the Natural Capital Account table.

STOCKS		GOODS & SERVICES				TOTALS
		RECREATION				
Natural capital stock	Stock extent	Total amount	Value	Ecosystem service	Value based on	TOTAL VALUE BY
Woodland	11254.00	202572.00	£730,693.06			£12,285,947.53
Other broadleaved woodland (not ancient)	7876.00	141768.00	£511,368.27	*all stocks*	*woodland*	
Coniferous	3378.00	60804.00	£219,324.79	*all stocks*	*woodland*	
Open water	234.00	4212.00	£8,263.62			-£54,068.61
Freshwater	185.00	3330.00	£6,533.21	*all stocks*	*open water*	
Saltwater	49.00	882.00	£1,730.42	*all stocks*	*open water*	
Mountain/heath/bog	3406.90	61324.20	£333,368.36			£1,042,458.86
Bog	26.00	468.00	£2,544.12	*all stocks*	*mountain/heath/bog*	
Heather grassalnd	356.00	6408.00	£34,834.93	*all stocks*	*mountain/heath/bog*	
Heather	3020.00	54360.00	£295,509.83	*all stocks*	*mountain/heath/bog*	
Inland Rock	4.90	88.20	£479.47	*all stocks*	*mountain/heath/bog*	
Improved grassland	34113.00	614034.00	£1,022,729.73	*all stocks*	*semi-natural grassland*	£1,155,576.83
Semi-natural grassland	17259.00	310662.00	£517,435.95	*all stocks*	*semi-natural grassland*	£2,378,681.71
Neutral	357.00	6426.00	£10,703.09	*all stocks*	*semi-natural grassland*	
Calcareous	0.00	0.00	£0.00	*all stocks*	*semi-natural grassland*	
Acid	16902.00	304236.00	£506,732.86	*all stocks*	*semi-natural grassland*	
Fen/marsh/swamp	0.00	0.00	£0.00	*all stocks*	*semi-natural grassland*	
All stocks	69890.20	1258023.60	£2,762,899.15			£22,897,518.81

Figure 4. Example of the Excel table structure used to record the full Natural Capital Account. Incomplete example for illustrative purposes only, only one ecosystem service and a selection of the habitat types are shown.

The Natural Capital Account table also contains information on the stock of natural capital supporting the provision of the flow of ecosystem goods and services valued. In the example above, the number of visitors per hectare was only available at the level of the entire National Park. As a result, information on the rate of visitation was recorded only at an aggregate level for all stocks combined. Similarly, information on the recreational value of each visit was available by habitat type, but not by habitat sub-class. For instance, the same recreational value was considered for broadleaved and coniferous woodland. Recording such information in the account table helps picking up some interesting nuances. We can, for example, observe that the difference in the total value of recreation provided by broadleaved and coniferous woodlands is driven only by differences in woodland extent (hectares of broadleaved and coniferous woodland), given that visitor numbers per hectare and value per visit are the same across both woodland types.

3.5 STEP 5: TESTING OF ALTERNATIVE ESTIMATES

After drafting the accounts, we focused on testing their sensitivity to the use of different estimates regarding the quantification of the underlying components of natural capital accounts, namely the Natural Capital stocks, the flow of ecosystem goods and services and the values. We compared how Natural Capital accounting results can vary when considering "standard practice" estimates versus other available, improved estimates. One of the purposes of the exercise was to highlight limitations in the currently employed approaches to Natural Capital accounting, and to suggest areas for improvement.

We tested several estimates linked to stocks, flows of goods and services and values. The choice of these sensitivity tests was driven by: a) a selection of issues of interest outlined by the National Parks Authorities; b) scientifically-relevant aspects identified by the research team; c) availability of alternative estimates to the ones used in the reviewed reports, offering opportunities for improvement and d) availability of local data to complement the "standard practice" methodology.

Each test of alternative estimates and its justification is presented and discussed in detail in section 4.3 in the Results section.

3.6 STEP 6: DISCUSSION AROUND ACCOUNT 'USEFULNESS'

In the concluding part of the project, we relied on stakeholders' consultation to discuss the usefulness of the produced "standard practice" Natural Capital accounts for decision-making. After presenting the draft accounts to the Chief Executives and other key staff of Dartmoor and Exmoor National Park Authorities, the research team facilitated a discussion (in a workshop setting) in which the merits and the limitations of the accounts were assessed. The discussion was particularly focused on understanding whether the produced Natural Capital accounts met the aspirations and expectations regarding the intended use of this method (as recorded in Step 1), and represent useful tools to better inform management and decision-making.

4 RESULTS AND DISCUSSION

4.1 REPLICATING THE "STANDARD PRACTICE" APPROACH FOR DARTMOOR AND EXMOOR

Starting from the "standard practice" approaches that practitioners have employed in the reviewed Natural Capital accounts, we have drafted a Natural Capital flow account for the year 2015 for Dartmoor and Exmoor National Parks. In Table 2 and 3, benefits are reported by ecosystem good and service (each column) and, where possible and applicable, also by the different natural capital asset classes (each rows). Total values are also provided by ecosystem service (bottom row) and by natural capital stock (right-hand column). A colour coded-approach was employed in each table. Green boxes show instances where ecosystem services could be valued successfully, red boxes where they could not. Orange boxes indicate a partial valuation (not all habitat-subtypes could be included). Grey boxes indicate that the ecosystem service in question is not provided by the corresponding habitat type. Blue boxes show the total values by habitat type (row totals) and by ecosystem service (column totals). The ecosystem services are separated according to whether they provide "private" benefits (obtained by individuals or organisations) or "public" benefits (delivered to the wider society). Please, note that certain ecosystem services (e.g. volunteering) deliver both private and public benefits, but are classed here as private benefits only. This is due to the fact that typical "standard practice" valuation methodology only captures the private benefits of this service (e.g. labour cost saved by an organisation), rather than also the public benefits (e.g. mental health benefits for volunteers). This issue is discussed in more detail later in this report. Appendices 7 and 8 provide full Natural Capital account tables for Exmoor and Dartmoor respectively, displaying annual quantities of ecosystem service delivery and valuation results (broken down by sub-habitat type, where possible). It also needs to be noted that the accounts for the two National Parks are not directly comparable, as different data and assumptions were used to quantify and value some of the ecosystem services (see for example Box 5 on the calculation of recreation values).

Table 2. Natural capital account for Exmoor National Park for 2015 (in 2015 GBP).

	PUBLIC BENEFITS			**PRIVATE BENEFITS**					
	Recreation	Climate regulation	Air quality	Timber	Livestock	Crops	Volunteering	Pollination	**TOTALS**
Woodland	731k	8953k	2175k	427k			X		***12285k***
Open water	8k	-62k					X		-54k
Mountain/heath/bog	333k	685k	23k				X		1042k
Improved grassland	1022k	X	133k				X		1155k
Semi-natural grassland	517k	1732k	129k				X		***2378k***
Arable	82k	-3183k	12k			1613k	X	7k	-1469k
Coastal	68k	31k	1k				X		100k
TOTALS	**2763k**	**8157k**	**2472k**	427k	**7258k**	1613k	199k	7k	**22897k**

Table 3. Natural capital account for Dartmoor National Park for 2015 (in 2015 GBP).

	PUBLIC BENEFITS			PRIVATE BENEFITS				
	Recreation	Climate regulation	Air quality	Timber	Livestock	Crops	Pollination	**TOTALS**
Woodland	3035k	9741k	2356k	456k				***<u>15588k</u>***
Open water	29k	-73k						-44k
Mountain/heath/ bog	4380k	540k	18k					*4939k*
Improved grassland	3337k	X	113k					*3450k*
Semi-natural grassland	4484k	3916k	291k					***<u>8691k</u>***
Arable	251k	-2539k	10k			1287k	6k	-986k
TOTALS	**15516k**	**11585k**	2788k	456k	**8194k**	**1287k**	6k	**39832k**

By replicating the "standard practice" approaches employed in the reviewed natural capital accounts, it was possible to estimate the monetised value of the following ecosystem services:

- Outdoor recreational opportunities;
- Carbon sequestration (from vegetation and plants)
- Air pollution removal (PM_{10} absorbed from the air by vegetation) and avoided related health damages
- Timber production
- Grazing activities (livestock)
- Crop production
- Pollination services (crop dependence on pollinators)
- Volunteering services (for Exmoor)[17]

[17] For Dartmoor, this information was not readily available in the public domain, and this gap was later filled by obtaining additional data directly from Dartmoor National Park Authority (discussed later in this report)

The value of some of the selected goods and services of interest could not be estimated – either because insufficient information was available on the quantity (flow) of ecosystem goods and services produced and/or because of a lack of available monetised estimates of the benefits. For example, no value was estimated for flood protection, wildlife and the provision of water for drinking water purposes - all undoubtedly highly important ecosystem goods and services supplied by National Parks. Incorporating the value of these ecosystem services could significantly increase the relative importance of the "public" compared to the "private" benefits estimated in Tables 2 and 3. For some of the above ecosystem goods and services filling the gaps would be possible by collating additional data, e.g. water extraction information could be obtained from local water companies. However, this process is likely complex and could lead to inaccuracies in the estimates: water companies do not specifically collect water extraction data for National Park areas only. Information is generally collected at specific water abstraction points, which often lie outside the National Parks' boundaries. For this reason, apportioning amounts and values of water to specific sites and catchments can be challenging.

Based on the results of the Natural Capital accounting exercise, we can show that Dartmoor and Exmoor National Parks provide a mixture of both public benefits (accruing to multiple individuals representing the entirety or some groups within society) and private benefits (accruing to single individuals or organizations). Public benefits exceed private benefits in both areas, although in Dartmoor they represent a higher proportion of total benefits estimated (driven largely by differences in the calculated recreation values). For Exmoor, the total benefits (for those ecosystem services which could be successfully valued) are estimated to be £23m, of which £9.5m are private benefits and £13.5m are public benefits; for Dartmoor, the total benefits account for £40m, of which £ 30m are public benefits and £10m are private benefits. It is important to note that this relative balance of private vs. social benefits is driven in large part by limitations in the 'standard practice' methodology, which leads to many public benefits, and therefore a large part of the natural capital value, being fully or partially overlooked. This is discussed in detail in the next section of the report.

In terms of the most valuable ecosystem goods and services provided (based on the results of the natural capital accounts), similar conclusions could be drawn for both National Parks. In both cases, the most valuable goods and services supplied include two public benefits (recreation and carbon sequestration) and one private good (livestock – although see discussion on the limitation of the livestock analysis later in this report). Slight differences exist, though, in terms of which ecosystem services were valued the most. On Exmoor, the highest values were estimated for climate regulation (£8.2m), followed by livestock (£7.3m) and recreation (£2.8m). For Dartmoor, recreational benefits were ranked first (£15.5m), followed by climate regulation services (£11.6m) and livestock (£8.2 – although see the discussion around livestock in section 4 for some important limitations regarding this estimate).

When we look at the total value of all considered ecosystem services by the different natural capital stock types (i.e. LCM land cover classes), again there are similarities and differences across the two case study areas. Both in Dartmoor and Exmoor, woodland habitats provide the highest measured benefits, followed by semi-natural grasslands – in both cases mostly due to the high values associated with carbon sequestration in those habitats. The magnitude of these figures, calculated using a Price x Quantity multiplication, is also driven by the amount of these habitats found within the National Parks (i.e. greater habitat extent contributes to increasing the total value associated with a given ecosystems). Interestingly, open water habitats and arable land are both associated with negative values. For example, in the case of arable land this provides useful insights into the negative impacts (carbon emissions), alongside the benefits provided (crop production).

4.2 LIMITATIONS AND SENSITIVITY OF THE ACCOUNT RESULTS TO ALTERNATIVE ESTIMATES

In this section, we discuss the limitations of producing "standard practice" natural capital accounts. We discuss issues around measuring stock extent and quantifying and valuing ecosystem service flows. We test the sensitivity of the Natural Capital Account results to using alternative estimates and suggest potential improvements to the "standard practice" approaches to overcome some identified limitations.

4.2.1 Measuring stock extent

The first step in the development of Natural Capital Accounts is to collect data on stock extent. Although some local data on Natural Capital assets was available for both National Parks, these data were spatially and temporally patchy. Therefore, in order to obtain information on the Natural Capital assets across the entirety of the National Parks at a set point in time, national data needed to be considered. In this study, we selected the CEH Land Cover Map 2015 (with some adaptations for Dartmoor National Park, see step 2 of the methodology), following the approach used in the DEFRA/AECOM Ecosystem Accounts for Protected areas. Using such national scale data, however, is subject to several limitations, which we discuss in turn in the sections below.

4.2.1.1 Level of detail

In the CEH land cover data, habitats are mapped into relatively broad classes, meaning that some ecologically relevant habitat variables are overlooked. For example, Ancient Woodland is not captured by the Land Cover Map dataset, despite being a habitat with unique features and providing a different flow of ecosystem services from regular broadleaved or coniferous woodlands. Ancient Woodland is not typically used for timber extraction, is particularly attractive for recreational purposes, and is of high biodiversity importance. Another habitat type which is overlooked by the Land Cover Map data is Rhos Pasture. In this study, we were able to merge local data on Rhos pasture with the Land Cover Map data for Dartmoor National Park (see section 2 and Appendix 4). Another example of a habitat feature which is overlooked by Land Cover Map data is Bracken cover. Understanding which areas are dominated by Bracken is important for upland management, as Bracken reduces the amount of foraging area available for livestock on the open moor, whilst having positive effects on certain bird and butterfly species. This potential effect of bracken on Ecosystem Services is currently overlooked in the Natural Capital Accounts and further efforts and data would be needed to identify Bracken-dominated areas across the National Parks, as well as needing a better understanding of the effects on ecosystem service flows. Beyond bracken, other habitat characteristics with management relevance are also not fully captured when using LCM data. This is the case, for instance, of gorse and other scrub on, for example, areas of heather grassland.

4.2.1.2 Classification accuracy

In addition to lacking detail on habitat types, national land cover maps can also present classification problems, and therefore reduced accuracy, when identifying natural capital stocks at finer spatial resolution. Hence, complementing national data with local knowledge is important for ground-truthing and increasing the validity and usefulness of data for management decisions. Box 1 highlights the potential impact of a habitat classification issues on account results.

Box 1. Testing sensitivity of results to classification issues

Exmoor National Park Authority staff highlighted that Land Cover Map data 2015 are subject to a major misclassification problem because they tend to classify Exmoor's open moors as acid grassland. In order to test how this misclassification affects account results, we tested what would happen if the classification was more accurate. To do that, we re-classified all acid grassland extent as "heather". Please note that in order to improve the accuracy further, an estimate would need to be obtained of the proportion of acid grassland which is misclassified. Such data are not available and, hence, we tested the effect of re-classifying the full acid grassland extent into heather. Please note that this is an extreme example, used only to illustrate the effect of habitat misclassifications on Natural Capital Account values; it is highly unlikely that all 100% of acid grassland on Exmoor is in reality heather, and further work would be needed to fully understand the extent of acid grassland misclassification.

The Land Cover Map 2015 data estimates that there are 16,902ha of acid grassland and 3,020ha of heather on Exmoor. After our re-classification, the total amount of heather habitat changed to 19,922ha, with no acid grassland. As a result of the habitat re-classification, the total Natural Capital account value changed from £22.9 million in the original account, to £26 million under the updated assumptions. The table below outlines the implications of habitat re-classification for the estimated amount and value of some ecosystem services. Only some ecosystem services (provided by acid grassland and heather) were affected by the re-classification (recreation, climate regulation and air quality). Other ecosystem services were unaffected, as these services are either not provided by the two habitat types (e.g. timber extraction), or because the ecosystem services flows and values were considered to be the same for both habitat types. The specific reasons explaining the detected changes in values for the affected ecosystem goods and services are outlined in the table below.

Ecosystem service	Original value	Value under new assumption	Reason for change
Recreation	£2.76M	£3.91M	Different value per visit to these habitat types
Climate Regulation	£8.16M	£10.10M	Difference in C capture between habitats
Air Quality	£2.47M	£2.46M	Difference in PM10 capture between habitats

Whilst acid grassland and heather are used as an example here, similar classification issues are likely to be present also for some other habitat types. For example, the Land Cover Map 2015 estimates a total extent of 26ha of blanket bog in Exmoor. Local work suggests that this is a significant underestimate (see https://www.exmoor-nationalpark.gov.uk/Whats-Special/moorland/exmoor-mires-project).

4.2.1.3 Repeatability issues

If the ambition is to produce natural capital accounts over multiple years, a key challenge is related to gathering comparable evidence over time. In order to detect variations over time and allow for the repeatability of the accounting process, data need to be collected using a consistent methodology, which is not always easily achievable in practice. Land Cover Map data are available for multiple years (1990, 2000, 2007 and 2015). However, due to changes in the protocol of satellite data imagery classification and modelling, comparing data over multiple years for the purpose of detecting changes in natural capital stocks is often problematic. Box 2 discusses some issues related to stock detection using 2007 and 2015 Land Cover Map data as an example. Between 2007 and 2015 significant changes were introduced in the training routine for land cover detection, measurement methods and algorithms used.

Box 2. Issues with stock change detection

In this test, we compared Land Cover Map 2007 and 2015 data for Dartmoor and Exmoor National Parks with the purpose of measuring changes in stock extent over time. To illustrate why the data are subject to limitations when the purpose is to repeat Natural Capital Accounts for another year, we focus on two habitats as case studies: broadleaved woodland on Exmoor and arable land on Dartmoor. LCM data appear to show that broadleaved woodlands on Exmoor have changed in extent from 5,764 ha (2007) to 7,821 ha (2015), suggesting an increase by 2,057 ha in less than 10 years. Similarly, data indicate that arable land on Dartmoor has changed from 10,694 ha (2007) to 2,182 ha (2015), signaling a decrease by 8,512 ha. In both cases, based on publicly available data or reports, no evidence could be found of such changes in stocks happening on the ground. A plausible reason for such differences between the two years could therefore be linked to variations in the methodological approach adopted in the Land Cover Map data classification across the two periods. To explore whether this is the case, we compare land cover classification based on Land Cover Map data with Google Earth's imageries (image A and D below), which allows us to see the current true habitat distribution. Based on this comparison, Land Cover Map 2007 data seem to do a better job with the classification of broadleaved woodlands (purple dots in image B) compared to Land Cover Map 2015 data (image C). As image C shows, in the LCM 2015 data, habitats other than broadleaved woodlands tend to be classified as broadleaved woodland (yellow dots). This is likely one of the reasons why broadleaved woodland figures in 2015 are so high relative to 2007. In 2015 LCM data, there is also a higher tendency to classify broadleaved or mixed woodlands as coniferous woodland (red dots), which suggests low accuracy in woodland classification routines.

A

B

C

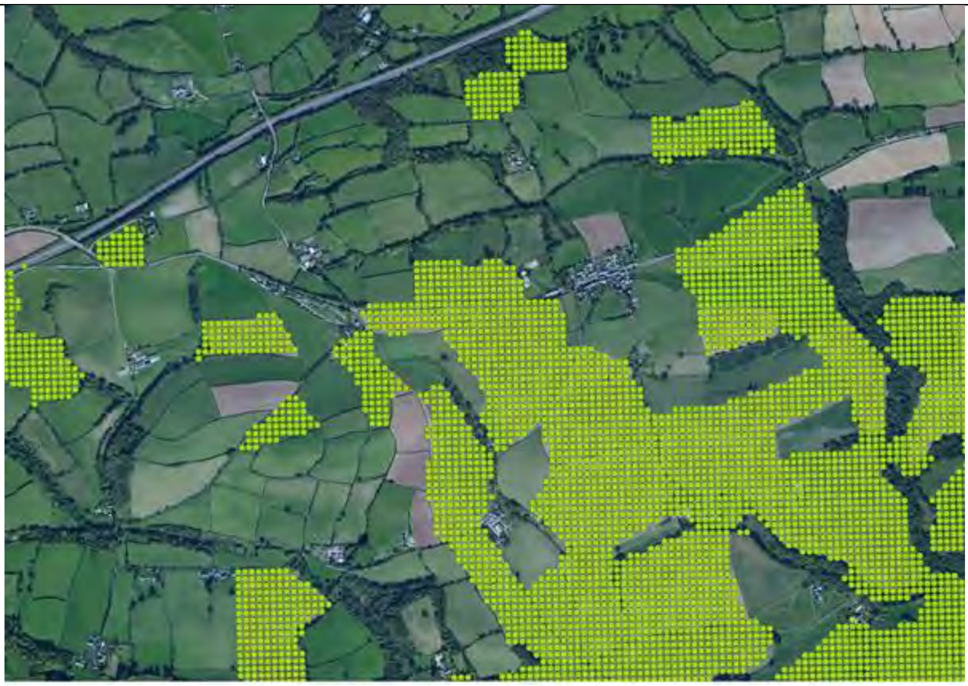
Clear classification problems can also be detected when comparing arable land cover on Dartmoor. Based on the example displayed on the next page, Land Cover Map 2007 data tend to classify other habitat types (especially grassland) as arable land (pink dots in image E). In 2015, the amount of land identified as arable appears to resemble reality more closely (yellow dots in image F). It is of course likely that some change in stock has taken place across time in both National Parks, but based on publicly available reports or data there is no evidence of the significant variations in land cover types suggested by the comparison between 2007 and 2015 Land Cover Map data. Hence, classification problems are apparent across the two years considered. It is possible that factors such as seasonality/timing or field rotation have not been adequately accounted/corrected for during the image acquisition and processing stages, causing these issues. Both factors may play an important role in the classification of arable land based on aerial images as fields might look very different depending on the day and month considered, and field configuration and use can be considerably different under different rotation schemes (Bryan et et al. 2009)[18]. A more accurate classification of Land Cover Map data for arable land could be based on CEH Land Cover plus Crops data, available for the period 2015-2018.

[18] Bryan, B.A., Barry, S., Marvanek, S. (2009). Agricultiural commodity mapping for land use change assessment and environmental management: an application in the Murray-Darling Basin, Australia. Journal of Land Use Science 4(3): 131-155.

D

E

F



To overcome these limitations in the level of detail, classification accuracy and repeatability, the National Parks would need fine-scale, park-wide data on land cover, split into habitat categories of management relevance. These data should also be collected consistently and repeatedly over time (e.g. annually) in order to allow for accounting and monitoring for changes in extents, flows and values over multiple years. Such data do not currently exist due to the time and cost involved in the data collection. However, the recent developments in high-resolution open-source remote sensing technology may help fill this data gap in a cost-effective way in the near future.

4.2.2 Measuring flows of goods and services:

The second step in the development of NCAs is to quantify the flows of ecosystem goods and services. In this section, we discuss factors relating to ecosystem service quantification which may limit the completeness and reliability of Natural Capital Accounts. We focus in particular on i) missing data, ii) the sensitivity of the accounts to using alternative available estimates, iii) the role of incomplete ecological information, iv) the effects of overlooking habitat condition and v) inadequately accounting for temporal dynamics.

4.2.2.1 Missing data

Missing data is a major limitation in the development of Natural Capital Accounts. For the ecosystem services Minerals, Plants and Seeds and Wildlife, no information on both the biophysical flows and valuation could be located. After a search of the literature and discussions with the National Park Authorities, it was decided not to explore Minerals and Plants & Seeds any further in this study, due to both the lack in data and limited management relevance (e.g. mineral extraction is not an activity which is pursued in National Parks). As conservation and enjoyment of the natural world are key purposes of National Parks, incorporating wildlife into the accounts was considered to be of substantial relevance to the National Park Authorities. The valuation of ecosystem services derived from wildlife was not attempted here due to the limited evidence and data availability, but is discussed in Section 4.2.3.1. However, the quantification of key wildlife supported by the different stock types was further explored (see Box 3 below) to help provide a baseline for future account improvements.

Box 3. Incorporating wildlife

Incorporating wildlife and biodiversity is a major challenge in the field of Natural Capital Accounting. The importance of wildlife to humans is widely appreciated, for example through recreational enjoyment, and the provision of ecosystem services such as pollination. Some of these benefits, such as recreation and game provision, can be estimated with current Natural Capital Accounting techniques when sufficient data is available. However, capturing biodiversity more generally is an ongoing challenge, both from an ecological and economic perspective. From an ecological perspective, it first needs to be determined which component of wildlife should be captured; this can include a wide range of measures regarding the abundance or conservation status of individual species, or the diversity of selected species or species groups. It then needs to be determined how such information links to ecosystem services enjoyed by humans, and subsequently how such benefits can be valued (see also section 4.2.3.1). Even when a suitable measure of biodiversity can be identified, data gaps remain a problem, with ecological survey records often patchy across time and space.

Currently, many organisations simply omit an estimate of wildlife from their accounts, or only quantify certain aspects of the wildlife "stock", without attempting valuation. For example, biodiversity was not discussed in the ONS Ecosystem Service Accounts[19], nor was it accounted for in the ONS scoping study for Mountain, Moorland and Heathland.[20] Other reviewed accounts attempt to acknowledge the importance of biodiversity using a wide range of different methodologies. The EFTEC woodland account[21] includes the extent of areas under designation as a proxy for capturing biodiversity, thus assuming that biodiversity is higher in areas subject to conservation action. In the EFTEC report, the limitations of the employed approach are clearly acknowledged. Biodiversity outside of protected areas is overlooked and improved indicators are proposed for the future, such as numbers of invasive species and numbers of native woodland species. The DEFRA/AECOM study on protected areas[22] used a different approach, where biodiversity was used as one of their indicators of ecosystem condition. Bird species diversity and abundance data from the British Trust for Ornithology (BTO) Breeding Bird Survey was reported as a biodiversity indicator for most, but not all, habitat types. Butterfly, fish and deer data were used for semi-natural grassland, open water and wetland, as well as mountain, moors and heath, respectively. Relevant ecosystem services supported by wildlife were discussed, but no attempts at quantifying service flows were made. The Nene valley report also attempted to incorporate estimates of biodiversity, using a broad collection of biodiversity records to produce "hotspot" maps.

[19] Office for National Statistics (2018). UK Natural Capital: Ecosystem service accounts 1997 to 2015

[20] Office for National Statistics (ONS) (2017). UK natural capital: developing UK mountain, moorland and heathland ecosystem accounts

[21] Cryle, P., Krisht, S., Tinch, R., Provins, A., Dickie, I., Fairhead, A. (2015). Developing UK natural capital accounts: woodland ecosystem accounts. Economics for the Environment Consultancy Ltd (Eftec) in association with Cascade Consulting for the Department for Environment, Food and Rural Affairs (Defra)

[22] White, C., Dunscombe, R., Dvarskas, A., Eves, C., Finisdore, J., Kieboom, E., Maclean, I., Obst, C., Rowcroft, P. & Silcock, P. (2015), 'Developing ecosystem accounts for protected areas in England and Scotland', Department for Food, Environment & Rural Affairs/The Scottish Government

However, such data were limited because observer biases were not controlled for and information was not disaggregated by spatial differences in survey efforts. Actual species richness information could therefore not be inferred from these maps, as ecological information is confounded with the survey biases. The RSPB Natural Capital report[23] provides a detailed discussion on the challenges and importance of incorporating biodiversity estimates into an organisation's Natural Capital framework. In their Natural Capital asset register, they annually record breeding numbers and changes in breeding populations for priority bird species on RSPB land, as well as an estimate of the proportion of the total national population that is supported by RSPB land. It is acknowledged that incorporating such information can be used meaningfully, alongside the monetary valuations in the account, to monitor whether the natural environment is being improved over time. One limitation is though that other species groups are not included due to the cost and effort associated with the necessary monitoring. Habitat quality (through measuring variables such as water quality, level of peatland degradation, plant richness and habitat fragmentation) could be used as a proxy for biodiversity (although it needs to be noted that habitat quality data is also often not available).

These examples illustrate that incorporating wildlife into the Natural Capital Accounting remains a challenge, with many different potential methodologies available. Which approach is useful for a Natural Capital Account for National Parks, will depend largely on the management decisions that the account should inform. Given that the statutory aim of National Parks is to conserve wildlife, an approach similar to that used by the RSPB would be a straightforward and informative way to monitor changes in abundance and status of key species year-on-year. Key species for such monitoring could be selected by the National Park Authorities to reflect important local wildlife and conservation aims. This could for example be done by adapting and expanding the current monitoring which takes place as part of the State of the Park reporting. We would recommend that such a list of species includes wildlife from a range of species groups and habitat types, and that species of both local and national conservation importance are considered. Such information can then be used alongside the Ecosystem Service and monetary valuation information in the Natural Capital Account, for example by setting a "net gain" management target with regards to the year-on-year biodiversity numbers in the account.

Whilst, as suggested above, selecting locally relevant wildlife species for monitoring in an organisation's Natural Capital Account is highly useful for management decision-making, this does limit the comparability between Natural Capital Accounts for different areas. In order to ensure that information can be compared across different areas, we would therefore recommend using additional biodiversity indicators obtained from national data. A wide range of national datasets on biodiversity are available from, for example, wildlife charities, however, such data often require further processing before regional or site-specific data can be obtained, and inclusion of these data may therefore not be an efficient and cost-effective option. The online tool NEVO developed by the LEEP institute at the University of Exeter, available at https://www.leep.exeter.ac.uk/nevo (see also box 6 on agriculture) is an example of a publicly available resource which can provide an additional metric of biodiversity. NEVO, which is a map-based tool, brings together spatially explicit data, natural science and economic models to provide insights into the integrated relationships between climate change, land use change, ecosystem service flows and economic values, and includes a dedicated component focusing on biodiversity. The tool allows users to extract a biodiversity index for areas, such as National Parks, in England and Wales. NEVO uses a JNCC species distribution modelling approach to estimate species richness in a given area, based on a comprehensive list of 100 species, covering birds, invertebrates, mammals, herptiles, plants and lichens. More information on the biodiversity emulation used in NEVO can be found at: https://www.leep.exeter.ac.uk/nevo/documentation/. This information can be readily used to explore differences in relative species diversity between different areas. In the table below, we illustrate these data, displayed as "numbers of species present/number of species included" for Dartmoor, Exmoor, the New Forest and the Brecon Beacons. The same 100 species are considered in each area, allowing for direct comparability. The

[23] RSPB (2017). Accounting for Nature: A Natural Capital Account of the RSPB's estate in England

NEVO tool can subsequently be used to explore the effect of future changes in land cover on species richness and a range of ecosystem services.

Species group	Dartmoor	Exmoor	New Forest	Brecon Beacons
Plants	22/38	21/38	26/38	28/38
Invertebrates	15/25	14/25	15/25	15/25
Birds	11/17	10/17	13/17	13/17
Mammals	9/14	9/14	10/14	10/14
Lichen	2/5	2/5	2/5	1/5
Herptiles	1/1	1/1	1/1	1/1
Total	**60/100**	**57/100**	**67/100**	**68/100**

Whilst species richness can be a clear indicator for management purposes, other key indicators (such as the status of key species of interest), also need to be incorporated into Natural Capital Accounts. This is due to the fact that some key habitats may provide a lower diversity of species, but are of substantial conservation value.

In addition to wildlife, other important gaps in the ecosystem services considered in the accounts concern e.g. game, drinking water and flood protection. For these, valuation data was available, but publicly available data to quantify the flow of ecosystem services was missing for both National Parks.

Suitable data on game and deer numbers extracted annually was not available for either of the National Parks – records were either outdated or, in the case of rod catch data for fish, it was not known how many of the caught animals were released back into the water. Following further discussions with the National Park Authorities, it emerged that game provision is of relatively minor importance for Dartmoor and was therefore not explored further due to limited management relevance. For Exmoor, game and deer extraction was not pursued further due to lack of data. Should data on numbers of game caught/shot become available in the future, including this ecosystem service in the Natural Capital Accounts will be very straightforward, as clear value information is available. However, the wider impacts of management for game shooting on other Natural Capital assets would still be overlooked; further work would be needed to incorporate such an assessment of wider costs of management for shooting (see discussion).

Flood Risk Regulation was of interest to the National Park Authorities, and was therefore studied in more detail upon completion of the “standard practice” accounts. However, no suitable methodology could be identified to fill this gap. This is due to the fact that flood risk mitigation is a complex ecosystem service and the extent of flood risk mitigation depends on the local land use, hydrology, geomorphology and wider ecology. Therefore, flood risk mitigation can only be quantified through the use of local, context- specific tools or models which take all these factors into account. This means that generalisable, “standard practice” solutions for quantifying this ecosystem service do not exist. Developing such models would likely be both time-consuming and costly, requiring substantial expert input from a range of sectors and academic disciplines.

Publicly available data on volunteering were missing for Dartmoor. To fill this gap, data on volunteer numbers needed to be obtained. Box 4 below illustrates how complementing publicly available datasets with data held within the organisation can improve account completeness.

Box 4. Filling gaps in "standard practice" accounts using local data

Local data on the number of volunteer days, whilst not available publicly, could be obtained from Dartmoor National Park to improve the account results.

Volunteering

Data on volunteering for Dartmoor could be obtained through information available as part of the National Park Family Indicators. Data show that a total of 2,601 volunteer days were organised or supported by the National Park in 2015/2016. Dartmoor also provided an expert estimate of the number of hours of work per volunteer day (5 hours). This allowed us using the "standard practice" valuation methodology (as used for Exmoor National Park's account) to value volunteering on Dartmoor. We calculated a total volunteering value of £95,048. No information was included on volunteering values in Table 3 for Dartmoor due to a lack of information on volunteering based on publicly available information. This example illustrates how additional local knowledge and/or data can be used to fill some gaps in the accounts when national estimates are not appropriate or when public data are not available. It is important to note that the above estimates of the amount of volunteering are not without limitations. We only include those volunteering days which are organised or supported by the Dartmoor National Park Authority; many other volunteering activities, unrecorded by the National Park, take place within the National Park boundaries, and the estimate of 2,601 volunteering days used here is therefore a lower bound estimate only.

4.2.2.2 Alternative assumptions

In many cases, a range of alternative assumptions regarding the amounts of provided ecosystem services can be considered when building Natural Capital Accounts. For example, based on the review of existing accounts, multiple alternative estimates are available for carbon sequestration and recreation (number of visitors), depending on the specific methodologies used and assumptions made in the source study. Which estimate is selected depends on a range of factors, such as the reliability of the underlying assumptions, the robustness of the data collected (strength of evidence) and the completeness and level of detail of the data for Natural Capital Accounting purposes (e.g. whether the estimates from the data source are available for each habitat type considered in the account). In Box 5 below, we test for the sensitivity of the account results to the use of alternative "standard practice" assumptions regarding climate regulation and recreation services.

Box 5. Alternative "standard practice" assumptions for the quantification of selected ecosystem services

Climate regulation

Measures of the flow of carbon sequestration services provided by natural capital have been found to vary substantially in the reviewed studies. This is because a range of scientific studies were considered and each of them used different habitat classifications, thus providing different estimates. For example, differences in the estimates are due to the inclusion of different plant species in the measurement of sequestration rates. Estimates also differed depending on whether CO_2 or CO_2e (CO_2 equivalent) was considered in the estimates of climate regulation services. CO_2e provides a more complete ecological picture of climate regulation benefits, as it also includes information on the sequestration of other gases in addition to CO_2, such as methane and nitrous oxide. In the "standard practice" account produced for the National Parks, we followed the RSPB Reserves estimates[24], as this was the only reviewed study providing information on CO_2e sequestration across most of the considered habitat types. Such an approach was therefore considered to be the most suitable choice, as it provides a more complete account.

In order to understand how sensitive the account results are to the use of different assumptions about carbon sequestration, we illustrate how the amount of CO_2 sequestration, and the resulting climate regulation value, vary when using different sequestration rates. In the table below, we show an example for Exmoor woodlands.[25] In all cases, the value per tonne of carbon being sequestered was kept the same as in the "standard practice" account and was based on the UK Government non-traded Carbon price. Therefore, all variations displayed are due to changes in the biophysical estimate of Climate regulation, thereby illustrating the sensitivity of the account to different assumptions on carbon sequestration rates.

Broadleaved woodland				
Carbon sequestration (tonnes/ha/year)	**Type**	**Assumption source**	**Total annual sequestration (tonnes/ year)**	**Climate regulation value**
10.71	CO_2e	RSPB Reserves	84,352	£5,263,109
9.37	CO_2e	Nene Valley	73,798	£4,604,606
4.97	CO_2	DEFRA/AECOM	39,142	£2,442,358
4.71	CO_2e	EFTEC UK Woodlands	37,096	£2,314,589

Coniferous woodland				
Carbon sequestration (tonnes/ha/year)	**Type**	**Assumption source**	**Total annual Exmoor sequestration (tonnes/year)**	**Climate regulation value**
17.51	CO_2e	RSPB Reserves	59,149	£3,690,566
12.13	CO_2e	Nene Valley	40,975	£2,556,629
12.66	CO_2	DEFRA/AECOM	42,765	£2,668,336
4.47	CO_2e	EFTEC UK Woodlands	15,100	£942,138

These figures show that when different carbon sequestration rates that are selected, the estimates of total sequestration by woodlands can vary by tens of thousands of tonnes, and the climate regulation value can vary by several million pounds. The RSPB Reserves estimate, based on the median carbon sequestration rates obtained from a review of the scientific literature, provides an adequate starting point for estimating National Park climate regulation benefits. The RSPB estimates are deemed a better choice compared to those presented in the DEFRA/AECOM account[26], as the DEFRA/AECOM account only considered for example the sequestration rates of

[24] RSPB (2017). Accounting for Nature: A Natural Capital Account of the RSPB's estate in England

[25] For additional information on this topic please see a past study conducted on Carbon sequestration in Exmoor woodlands, based on the 1999 Forestry Commission National Woodland Inventory: https://www.exmoor-nationalpark.gov.uk/__data/assets/pdf_file/0027/185418/Exmoor-Woodland-Carbon-Final-Draft-Report.pdf

[26] White, C., Dunscombe, R., Dvarskas, A., Eves, C., Finisdore, J., Kieboom, E., Maclean, I., Obst, C., Rowcroft, P. & Silcock, P. (2015), 'Developing ecosystem accounts for protected areas in England and Scotland', Department for Food, Environment & Rural Affairs/The Scottish Government

one broadleaved and one coniferous species, and overlooked gases other than CO_2 entirely. In the EFTEC[27] and Nene Valley study[28], sequestration rates were only provided for few habitat types, and would therefore not provide account completeness. In order to improve the estimates obtained from the RSPB Reserves Account, local data could be collected on the exact species and age composition of National Park woodlands, in order to derive more locally specific estimates of sequestration rates from the scientific literature.

Recreation

To calculate the number of visitors and recreational value on Exmoor, STEAM data were used (following the methodology outlined in the DEFRA/AECOM report[29] and several others). For Dartmoor, an alternative estimate of recreationists' numbers could be obtained using the ORVal model. We here compare the impact of using different visitor number estimates on the calculated recreational values. The valuation methodology is kept constant.

Data source	Visitors/hectare	Recreational value
ORVal	69	£15,516,527
STEAM	21	£13,687,065

The table shows that these different data sources provide very different visitor numbers and recreational values. Such variations in the numbers and values are due to differences in the modelling methodology. For example, STEAM includes only visits of over four hours, whereas ORVal includes shorter visits also. It is therefore deemed that ORVal provides a more accurate picture of the total recreational numbers, however, STEAM figures can be used to compare Dartmoor visitation rates with those in other National Parks and protected areas which use only STEAM estimates.

In Box 5 above, we test for the sensitivity of the NCA results to the use of different estimates available from national datasets. Occasionally, there may be both national averages and context-specific data available, or accounts can be improved by adapting the national estimates with local information. In Box 6 below, we test how account results can change when locally relevant data or knowledge is incorporated.

Box 6. Incorporating context-specific information

Volunteering

In the accounts presented in Table 2, an 8-hour working day was assumed for volunteers on Exmoor. Subsequent discussions with National Park Authority staff indicated that volunteer working days on Exmoor are generally shorter (5 rather than 8 hours). When we improve the account by taking into consideration this local information, estimates of annual volunteer hours change from 27,288 to 17,055, with the value of volunteering changing from £199,436 to £124,648.

Crop proportions and agriculture

When discussing the initial account findings with National Park Authority staff, it was clear that the national figures on agricultural land use, used to break down the total arable land into crop types, are not readily applicable to

[27] Cryle, P., Krisht, S., Tinch, R., Provins, A., Dickie, I., Fairhead, A. (2015). Developing UK natural capital accounts: woodland ecosystem accounts. Economics for the Environment Consultancy Ltd (Eftec) in association with Cascade Consulting for the Department for Environment, Food and Rural Affairs (Defra

[28] Rouquette, J.R. (2016). Mapping Natural Capital and Ecosystem Services in the Nene Valley. Report for the Nene Valley NIA Project.

[29] White, C., Dunscombe, R., Dvarskas, A., Eves, C., Finisdore, J., Kieboom, E., Maclean, I., Obst, C., Rowcroft, P. & Silcock, P. (2015), 'Developing ecosystem accounts for protected areas in England and Scotland', Department for Food, Environment & Rural Affairs/The Scottish Government

Dartmoor and Exmoor. This is because agricultural land use in the two National Parks is very different from the national average. For example, crops such as beans are generally not found within the National Park boundaries. Based on expert opinions, following discussion with National Park Authority staff, other crop types were also over- or under-represented. Data from the DEFRA June Survey Agricultural cut for National Parks[30] was reviewed in order to identify improved estimates of the proportions of different crop types on DNPA and ENPA arable land. However, the problem with these data is that they are broken down only into a limited number of categories (i.e. "cereals", "other arable crops" and "horticultural crops") and such a breakdown is therefore not sufficient to derive information on yields and values for specific crop types in our case study areas.

In order to test how sensitive the Natural Capital Accounts are to different assumptions on the proportion of different crop types on arable land, we derived information on crop proportions within each National Park using the NEVO tool (https://www.leep.exeter.ac.uk/nevo). NEVO is "a map-based decision support tool to inform decisions that affect the natural environment of England and Wales". NEVO estimates crop types using underpinning data from the Farm Business Survey[31]. For both Dartmoor and Exmoor, we converted the extent of crop types (as provided in NEVO) into percentages and compared these against the national percentages used in our "standard practice" accounts (presented in Tables 2 and 3). The results of this comparison are outlined in the table on the following page. It has to be noted that NEVO uses fewer crop categories, as potatoes were not separated into "early" and "late", and linseed, oats, peas and field beans were not included (and therefore aggregated into the "other" category).

It is important to also note that in the standard practice accounts (Tables 2 and 3), not all crops are included in the valuation of agricultural crop production. For example, during one of the workshops, National Park Authority staff queried why maize was not included. This is due to the fact that following the standard practice approach, yield data were derived from DEFRA publications (cereal and oilseed rape harvest data)[32], and no information on maize yields could be identified in the publicly available DEFRA datasets. As no improved information on maize crop proportion could be derived from the NEVO tool, maize yield was not explored further. However, should more complete information on crop types within the National Park boundaries become available (e.g. through local surveys), information on yields of additional crops could be derived from the scientific literature, for example, or through further exploring DEFRA documentation not currently publicly available.

Crop type	% of arable land based on national data	% of Dartmoor arable land based on NEVO	% of Exmoor arable land based on NEVO
Wheat	44.2	26.7	21.6
spring barley	9.7	13.4	13.0
winter barley	9.8	8.6	8.3
oilseed rape	16	16.9	13.0
sugar beet	2.4	0	0
potatoes early	0.3	0.03	0
potatoes late	2.2		
Linseed	0.4		
Oats	2.6		
Peas	1.1	34.4	44.0
field beans	4.3		
Other	7		

[30] DEFRA June Survey statistical data set geographical breakdowns, available at: https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june

[31] Further information on the Farm Business Survey: https://www.gov.uk/government/collections/farm-business-survey

[32] Defra Cereal Production survey & Defra Oilseed Rape survey data: https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june

This table illustrates that there are some substantial differences between national data and NEVO estimates of crop proportions on arable land. In particular, the estimates of wheat produced on Dartmoor and Exmoor are lower in NEVO, compared to the national averages based on DEFRA data. The proportion of "other", unspecified, crops is significantly higher. To test how different estimates of crop proportions can change the account results, we compare the crop proportions based on NEVO with those based on the national estimates used in the standard practice account.

Dartmoor				
Crop type	**Total production (tonnes) – account proportions**	**Total production (tonnes) – NEVO proportions**	**Value – account proportions**	**Value – NEVO proportions**
Wheat	7804	4719	£1,555,106	£940,310
spring barley	1168	1608	£208,782	£287,580
winter barley	1519	1333	£271,686	£238,310
oilseed rape	1287	1365	£457,778	£485,515
sugar beet	3109	0	£100,393	0

Exmoor				
Crop type	**Total production (tonnes) - account proportions**	**Total production (tonnes) - NEVO proportions**	**Value – account proportions**	**Value – NEVO proportions**
Wheat	9786	4787	£1,949,940	£953,867
spring barley	1464	1958	£261,791	£350,132
winter barley	1905	1612	£340,666	£288,206
oilseed rape	1613	1317	£574,006	£468,664
sugar beet	3898	0	£125,882	£0

As NEVO did not include an estimate for all of the crops considered in the standard practice account, we cannot directly compare the total value of crop production between the two approaches. However, we can compare the estimates of production and value for the five crops (wheat, spring barley, winter barley, oilseed rape and sugar beet) which were included in both the standard practice and NEVO estimates of crop production. For barley, oilseed rape and sugar beet, variations in the figures are relatively minor between the two approaches, with production varying by several hundred tonnes only. However, wheat production amounts, and the resulting values, are very different between the national and NEVO estimates of crop proportion. Wheat production is overestimated when using national estimates of crop proportions. As land allocated to wheat production in uplands on Dartmoor and Exmoor is likely lower compared to the national average, NEVO estimates seem to represent a more realistic picture of true crop production for our case study areas. However, the downside is that using NEVO rather than national estimates only allows to focus on a smaller subset of crop-types. In order to improve the standard practice approach whilst still focusing on a more complete list of crop types, we would recommend replacing national estimates with real data, by collecting information on the exact crop areas within the National Park boundaries.

During the production of the standard practice accounts for Dartmoor and Exmoor, quantifying the value of livestock proved challenging. An additional test that was therefore performed concerning the effect of considering alternative approaches for the quantification of livestock production for natural capital accounting purposes (box 7).

Box 7. Testing for alternative quantifications of livestock

We attempted to replicate the methodology adopted by the reviewed natural capital accounts to quantify the flow of livestock. However, replicating the existing approaches was not possible due to insufficient information provided in the reviewed accounts regarding the adopted methodology. Whilst it was possible to obtain information on the total number of livestock, quantification of the annual flow of livestock as an ecosystem service was not possible (due to insufficient detail provided in the reviewed reports, meaning that calculations could not be replicated). We initially assumed that the annual flow of benefits linked to livestock corresponded to the value (measured in terms of farm gross margins) provided by the sale of the total number of livestock present in a given year on Dartmoor and Exmoor. This is however a poor assumption, given that some livestock takes multiple years to mature, and other adult animals are kept solely for breeding purposes. We therefore tested for the effect on the account numbers and values of excluding livestock that we could assume may not have value (in the accounting sense of the word). In the accounts presented in Tables 2 and 3 the following livestock types were included in the total livestock counts (based on DEFRA June survey data[33]): dairy herd, beef herd, calves, other cattle (no valuation available), breeding pigs, other pigs (no valuation available), breeding ewes, lambs, other sheep (no valuation available), fowl, other poultry (no valuation available), goats (no valuation available) and horses (no valuation available). In our test of assumptions (below), we excluded those animals which are, or assumed to be, breeding animals, namely breeding pigs, breeding ewes and other cattle.

	based on total numbers present		excluding livestock for (likely) breeding purposes	
	Total animals	**Value**	**Total animals**	**Value**
Dartmoor National Park	282,088	£8,193,537.42	168,788	£5,093,923.29
Exmoor National Park	362,840	£7,257,878.66	231,523	£3,401,148.79

Excluding the breeding livestock understandably decreased the total number of livestock, and led to a lower value of livestock production. This may be an improvement on the original account values, as it is no longer assumed that all animals produce value each year. We believe that excluding breeding livestock is a more credible and conservative approach, compared to the one initially adopted, which assumes that all livestock on Dartmoor or Exmoor are sold or slaughtered on a yearly basis. However, in the absence of data on the exact number of livestock produced and sold on the market for the year of interest, only including non-breeding livestock, may still lead to an over-estimate of annual production (e.g. by not taking into account that some animals take longer than one year to mature and that some lambs and young cattle may be retained for future breeding rather than marketed).

We can also compare this against the livestock estimates produced by NEVO for beef, dairy and sheep, which incorporates annual livestock yields into the calculations (see box 6 for details on NEVO). In the table below, we therefore look at the Dartmoor and Exmoor account estimates for non-breeding beef, dairy and sheep only, to ensure comparability with NEVO.

	NEVO livestock predictions		Account predictions	
National Park	**Total beef/dairy/sheep**	**Farm livestock profits**	**Total beef/dairy/sheep**	**Value**
Dartmoor	161,900	£6.7m	113,679	£5,074,059.21
Exmoor Park	185,300	£5.5m	149,426	£3,388035.73

[33] DEFRA June Survey statistical data set geographical breakdowns, available at: https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june

Differences between NEVO and the initial account estimates (Tables 2 and 3) are likely due to differences in the underpinning data and differences in the classification of animals into breeding and non-breeding livestock. However, figures are not dissimilar between NEVO and the "standard practice" approach and are of a similar magnitude.

4.2.2.3 Incomplete ecological information

When reviewing published account studies and reports, it was clear that the methodology for quantifying biophysical flows of ecosystem services is often highly simplified, thereby overlooking ecologically important factors. For example, when calculating climate regulation benefits, current accounts differ in whether they use an estimate of CO_2 or CO_2e (CO_2 equivalent). When considering CO_2 only, the sequestration of greenhouse gases other than CO_2, such as methane (CH_4) and nitrous oxide (N_2O), is overlooked. Box 5 provides an estimate of the sensitivity of the account results to the consideration of different estimates. Similarly, when focusing on air quality, a range of different particles can be considered in the account. For Dartmoor and Exmoor, we only focused on PM_{10}, but ecological completeness could be improved by also considering other air pollutants, such as Nitrous Oxide, $PM_{2.5}$ etc.

As discussed previously, the estimation of flood risk mitigation can only be realistically improved through the development of local or regional, context-specific modelling and tools for flood protection in relation to different land uses and geographical locations. This is another example of an ecosystem service for which incomplete ecological information limits the comprehensiveness of the Natural Capital Account.

It needs to be acknowledged that "standard practice" approaches tend to overlook a wide range of ecologically complex, but nonetheless crucial, interactions between the natural environment and the provision of ecosystem services. Examples include numerous parasitic wasp species, supporting ecosystem service provision through links with a wide range of other organisms, but also potentially acting as crop pests. Another example includes honeybees and heather, which together provide culturally important products such as heather honey.

4.2.2.4 Overlooking ecosystem condition

When developing a Natural Capital Account, ecosystem condition is often partly or completely overlooked. This can lead to substantial limitations and gaps in findings. For example, in our case studies, the Climate regulation services provided by bogs/peatlands could not be estimated. Depending on peat condition, peatlands can range from net carbon emission (when in poor condition) to net carbon sequestration (when in good condition). National Park Authority staff and peatland experts at the University of Exeter were consulted, but appropriate data on peat condition could not be obtained for Dartmoor and Exmoor. For this reason, climate regulation services was data deficient for this specific habitat type.

Other examples of environmental services where different ecosystem conditions can play a role, include: drinking water (susceptible to the level of water quality), recreation (with visitors preferring habitats in better ecological condition) and timber (available timber quantity and quality is driven by woodland quality).

4.2.2.5 Accounting for aspects related to temporal dynamics

When building natural capital accounts, temporal aspects should be taken into consideration. In most cases, the standard practice methodology just focuses on the amount of goods and services that natural assets provide over the period of one year (flow account). Alternatively, if the desire is to produce an asset account, it is necessary to look into the quantity of goods and services that natural capital supplies into the future. Renewable goods and services such as Carbon sequestration could in principle be provided indefinitely as long as the habitat is in existence, whereas "non-renewable" goods, such as oil and gas, can only be supplied for a limited number of years until the stock is depleted. It is therefore necessary to establish the total number of years over which each given habitat will produce the ecosystem services of interest. This timeframe is often challenging to estimate and relies on some approximations. The choice of this time horizon can affect the calculated account values (see section 4.2.3.4.).

Over time, it is not only natural capital stocks which change, but the amount of ecosystem service flows and beneficiaries can also vary. For example, crop yields and timber extraction may differ between years and there may also be changes over time in the number of beneficiaries and users of the environmental goods and services of interest (e.g. due to local population growth). Often, an average or outdated figure is used across years, which may mis-represent the actual ecosystem service flows or number of beneficiaries (see box 8). Therefore, when producing a revised Natural Capital Account for a new year, it is essential not only to revise stock extents, but also to check whether any of the ecosystem service flow quantifications need updating with more recent figures.

Box 8. Testing the effect of population changes over time: the case of recreation

One example where population changes can play a particularly important role is in the case of recreation services. Increases in the number of people that have potential access to a recreational area can translate into an increase in the number of beneficiaries/users/visitors.

In the case of Dartmoor, for example, the total number of visits (modelled using the ORVal tool) is estimated to have increased by almost 3% (from 7,765,103 to 7,991,417) over the period 2014 to 2019, due to increases in the number of houses and local population. Therefore, if a new account was to be produced for a new year, not updating the visitor numbers compared to an earlier account, would lead to an underestimation of total recreational benefits. This is illustrated in the table below by comparing visits between 2014 and 2019 by habitat type.

	Visits 2014	Visits 2019	Variation	
Woodlands	2,455,382	2,520,322	+64,940	+2.64%
Moors and heath	2,186,629	2,262,525	+75,896	**+3.47%**
Managed grassland	1,332,341	1,364,400	+32,059	+2.41%
Natural grassland	1,037,666	1,073,501	+35,835	**+3.45%**
Rivers and lakes	403,807	413,236	+9,430	+2.34%
Graves and cemeteries	180,552	413,236	+4,151	+2.30%
Agriculture	166,477	170,450	+3,974	+2.39%
Allotments	2,250	2,280	+30	+1.33%
	7,765,103	**7,991,417**	**+226,314**	**+2.91%**

4.2.3 Measuring economic values of goods and services:

The "standard practice" methodology has given insufficient or no consideration to certain aspects that can substantially influence the economic values that people derive from the environment. In the following sub-sections, we discuss a series of factors that have to date been overlooked or insufficiently accounted for by the reviewed "standard practice" approaches. Where possible, we use examples to illustrate the consequences of inadequately or limitedly considering such aspects when building Natural Capital Accounts.

4.2.3.1 Missing economic values

Natural Capital accounting practitioners often fail, or are unable, to include a variety of ecosystem good and services that provide important value flows to people. Based on our exercise, for instance, the benefits provided to society in relation to the existence of plants and animal species, beautiful sceneries and unique/diverse landscapes, as well as the appreciation of cultural heritage are completely missing from recent natural capital accounting case studies. This is a particularly significant gap especially if the goal is to develop natural capital accounts for protected natural areas and National Parks, where wildlife, landscape and cultural heritage represent important components of the flows of ecosystem goods and services provided and are significant factors in land management decision-making. As explained in more detail in Box 9, the main reason why such goods and services are not commonly included in standard practice Natural Capital Accounts is that they are difficult to quantify and value. The benefits generated by rare and biodiverse flora and fauna species, beautiful landscapes, historic artefacts or archaeological remains are generally not captured by or connected to any market transaction and therefore is not recorded in the economy. As explained in more details below, the estimation of the economic values associated with biodiversity, scenery or cultural heritage requires tailored valuation approaches and methodologies remain largely under-developed. This means that, with the current state of knowledge, only some of the gaps identified within the "standard practice" natural capital approach can be filled. More research is required in the future to develop appropriate techniques to estimate such under-researched and missing economic values.

Box 9. Missing economic values

Biodiversity: In the System of Experimental Environmental Accounts (SEEA) biodiversity is defined at three different levels: genes, species and ecosystems. Whilst aspects of biodiversity-related services (e.g. game hunting) are sometimes covered in the accounts, this is not the case for other (perhaps less tangible) ecosystem services provided by biodiversity. Biodiversity is important and valued by people for other reasons, such as:

i) the provision of non-consumptive recreational benefits (e.g. wildlife watching);
ii) the maintenance of the functioning of ecological systems and supporting the production of all goods and services that natural capital provides; and
iii) other "non-use value" reasons related to the need to preserve biodiversity and species for their "intrinsic" importance and for future generations.

The above values could be calculated following different routes. Valuing i) could be achieved, for instance, by focusing on the tourist expenditure that visitors are willing to incur to see specific species. For an example of such an approach, we refer to the RSPB report on the value of golden eagles (Molloy (2011)[34] and RSPB (2010)[35]). Alternatively, another, more accurate, approach would consist of using a travel cost recreational demand model with wildlife as one of the attributes of the visited site. Much more complex and contested than estimating the value of i) is the estimation of the value of ii) and iii) (ONS, 2017)[36]. Firstly, as outlined in Box 3, biodiversity refers to a variety of life forms, but it is a complex concept which can be measured in many different ways using a variety of metrics (for example diversity and/or abundance, and considering different levels such as the genes, species, species groups or ecosystems). Previous studies have attempted to estimate the value of specific (keystone or iconic) species, which only represent a sub-set of all species that form biodiversity. Secondly, a further challenge is related to the existence of moral arguments against the valuation of biodiversity. There are some concerns that monetizing biodiversity could lead to an under-appreciation of the intrinsic importance of the environment and to a commodification of nature. For example, valuation is criticised for not being able to account for the critical biodiversity thresholds that should not be passed to avoid undermining the existence and functionality of entire ecosystems (however, as outlined in box 3, a "no net loss" or "net gain" approach could be employed to overcome some of these concerns). In such a framework, where the valuation of biodiversity emerges as a complex and inappropriate task, alternative non-monetary approaches could also be put in place to understand the 'value' that society places upon biodiversity conservation. These include stakeholders' consultations that can help to identify biodiversity conservation targets. This approach does not include monetisation, but is a legitimate alternative expression of societal values (Mace et al. 2019).[37] An alternative view is supported by the SEEA, which recommends estimating the benefits of biodiversity as the value of all goods and services that biodiversity supports. Another possibility is also to consider biodiversity as a characteristic of ecosystem assets and an indicator of asset condition, which determines the flow of goods and services supplied by the natural capital (ONS, 2017)[38]. However, the links between biodiversity, asset condition and ecosystem service flows cannot be easily untangled and low-diversity habitats can still provide key ecosystem services.

Landscape (scenic values): Landscape-related values have also been largely overlooked in natural capital accounts. Complex, unique and/or diverse landscape offer spectacular views that can be enjoyed by recreationists or residents.

[34] Molloy, D, 2011. Wildlife at work. The economic impact of white-tailed eagles on the Isle of Mull. The RSPB, Sandy.
[35] https://www.rspb.org.uk/globalassets/downloads/documents/positions/economics/the-local-value-of-seabirds.pdf
[36] ONS (2017). Principles of Natural Capital Accounting. A background paper for those wanting to understand the concepts and methodology underlying the UK Natural Capital accounts being developed by ONS and Defra.
[37] Mace, G. (2019). The ecology of natural capital accounting. Oxford Review of Economic Policy, 35(1): 54–67.
[38] ONS (2017). Principles of Natural Capital Accounting. A background paper for those wanting to understand the concepts and methodology underlying the UK Natural Capital accounts being developed by ONS and Defra.

To capture this value flow, different approaches could be considered. A travel cost approach could be employed to capture the recreational value of landscape views; information on scenic features (e.g. waterfalls, caves etc.) and viewing points could be employed to explain the choices of visited sites by recreationists and to estimate the extra value that visitors experience from accessing an area with scenic views or viewing points. Similarly, information on viewing points and scenic features can be used as an explanatory variable in hedonic price models. The underlying assumption in these models is that people's choice for a residential location depends on the characteristics of the property, but also on some environmental qualities of the place, which are factored into the price of properties. Hedonic price analyses are, though, data- and resource-intensive. They require a considerable amount of detailed property, geographical and environmental information that is not always easily accessible or available. Furthermore, this approach relies on substantial econometric and statistical work, which requires specific skills and significant amounts of time which is not always available within the scope of most natural capital accounting projects.

Cultural heritage: whilst cultural heritage and archaeological artifacts are appreciated by people, to date, the historic environment has been poorly represented in ecosystem services and natural capital accounts (Historic England, 2017).[39] People can appreciate the historic environment, for example because it enhances their recreational experience, and there are methods available to estimate such value. Cultural heritage could be considered as yet another feature of the visited recreational site which can contribute to enhancing the visitors' experience. Information on the presence of historic buildings (e.g. castles, country houses etc.) and archaeological sites (e.g. standing stones, burial mounds etc.) could be incorporated into travel cost demand models to understand how recreationists choose between different recreational locations and what role the availability of specific archaeological features has in their decision. People might also value historic monuments and artifacts because they symbolise the culture, traditions and sense of place of an area and as something that needs to be passed on to future generations. Estimating these values is admittedly more challenging, even if some studies have attempted to do so,[40] and requires the consideration of welfare, rather than exchange values, not necessarily compatible with natural capital accounting principles.

4.2.3.2 Partially missing economic value components

Whilst recent natural capital accounting case studies have tended to completely overlook the value of some environmental goods and services, they have also managed to value the benefits provided by other goods and services relatively well. In some cases, though, the values considered in the accounts only provide a partial quantification of the benefits that the environment provides to people. This is the case, for instance, with the value of flood risk regulation. The value of reducing flood risks is not often considered in "standard practice" approaches (probably because, as explained previously in this report, quantifying the reduction in flood risk events attributable to the presence of natural capital assets is very difficult). Only one of the reviewed reports (Smithers et al. 2016)[41], reported information on the benefits of reducing flood risks by estimating the avoided costs (flood-related expenditures) resulting from

[39] Historic England (2017). Ecosystem services, natural capital and the historic environment

[40] Kuhfuss, Hanley, Whyte (2016). Should historic sites protection be targeted at the most famous? Evidence from a contingent valuation in Scotland.
Willis et al. (2009). Assessing Visitor Preferences in the Management of Archaeological and Heritage Attractions: a Case Study of Hadrian's Roman Wall. Int. J. Tourism Res. 11, 487–505

[41] Richard Smithers, Outi Korkeala, Guy Whiteley, Shaun Brace, Bex Holmes (2016). Valuing flood-regulation services for inclusion in the UK ecosystem accounts. Ricardo Energy & Environment for the UK Office for National Statistics

the adoption of natural flood mitigation measures. These estimates, though, completely overlook the benefits associated with preventing flooding episodes and avoiding the associated mental health distress and threats to life. Such benefits, researched elsewhere, can be very substantial (Fujiwara et al. 2013)[42]. In this sense, focusing only on avoided flood-related defence costs only provides a lower bound estimate of the total value. Box 10 below focuses on the case of volunteering benefits, which are only partially accounted for in "standard practice" approaches.

Box 10. Partially missing economic values

Volunteering health benefits

Volunteering is not often accounted for in "standard practice" natural capital accounts. However, there are several benefits associated with volunteering. An obvious one is in terms of cost savings for the organisation, which benefits from free labour to carry out tasks which otherwise would have relied on paid workers. To quantify the value of volunteering in those terms, one approach consists of estimating the wage-equivalent value of volunteer work. Practitioners often multiply the hours spent volunteering by some estimate of hourly wage rates (by skill level). This approach is the standard method employed, for example, by the Heritage Lottery Fund (HLF) to cost volunteers' input into projects. The HLF employs different rates to value volunteers depending on the skills: a rate of £6.67/hour (or £50 a day) is considered for unskilled volunteers who, for instance, are in charge of clearing a site or acting as a steward at an event; for skilled workers (e.g. leading a guided walk) a rate of £20/hour (or £150 a day) is used; for professional services (e.g. accountancy or teaching) a rate of £50/hour (or £350 a day) is usually considered.[43]

Following "standard practice", we used the HLF figures for hourly unskilled labour (£6.67/hour) (conservative approach) and have assumed 5 hours of volunteering work per day (improved estimate based on stakeholders' consultations, see box 6). The number of volunteering hours per year were obtained starting from the number of volunteer days provided by Exmoor and Dartmoor National Parks[44], multiplied by 5.

	Exmoor National Park	Dartmoor National Park
Total volunteering days (per year)	3,411	2,601
Total number of volunteer hours	17,055	13,005
Value of volunteering (2015)	£124,648	£95,048

There are some discrepancies, though, between the above approach and the one usually employed by the National Park Authorities to value volunteering activities. This latter is based on the assumption that half of volunteering days should be valued at £100/day and the other half at £50/day. Such figures only approximate the official HLF figures and there is no particularly strong argument to justify the use of those numbers (sources could not be traced, the £100/day figure possibly represents an out-of-date proxy for the £150/day HLF figure for skilled volunteering). For comparative purposes, we report below the value of volunteering based on the approach commonly employed by National Park Authorities.

[42] Fujiwara, D., Oroyemi, P., McKinnon, E. (2013). Wellbeing and civil society. Estimating the value of volunteering using subjective wellbeing data. A report of research carried out by the Department for Work and Pensions and the cabinet Office.

[43] http://www.cavs.org.uk/wp-content/uploads/2012/04/4.19.pdf
https://www.heritagefund.org.uk/sites/default/files/media/attachments/HF%20Application%20Guidance_C_LARGE_0.pdf

[44] It's important to note that the estimate of the number of volunteer days for both National Parks should not be compared, as for Dartmoor the figure provided only includes volunteering that is organised by the National Park, which underrepresents the actual level of volunteers on Dartmoor.

	Exmoor National Park	Dartmoor National Park
Total volunteering days (per year)	3,411	2,601
Value of volunteering (2015)	£255,825	£195,075

Both approaches considered in this Box provide a lower bound estimate of the value of volunteering. It is well-known that a considerable portion of the benefits of volunteering accrue to the volunteers themselves in term of health and well-being benefits (Casiday et al. 2008).[45] There is not much literature available on these benefits, but some studies found that volunteering reduces the incidence of depression, stress, hospitalisation, pain and psychological distress. It is difficult to put precise numbers on those benefits. However, some estimations have been attempted. New Economy Manchester (2014)[46] estimate that the average cost of treating those suffering from depression or anxiety is around £956 per year. Volunteering could reduce or fully prevent depression or anxiety problems. Hence, the provided figure, which is an estimate of the yearly avoided costs for the NHS to treat mental health problems, could be viewed as an additional estimate of volunteering benefits. As well as reducing treatment costs for the NHS, spending time outdoor volunteering also provides mental health benefits to volunteers that translate into additional wellbeing. These benefits have been found to account for a large component of the value of volunteering. As reported in Haldane (2014)[47], some studies (Fujiwara et al. 2013; Fujiwara et al. 2014) have estimated that the increased life satisfaction and wellbeing resulting from frequent volunteering is worth around £13,500 per year (2011 prices) and the relief from depression and anxiety as a result of volunteering is worth around £37,000 per year. Such estimates could be considered as an upper bound value of the health benefits of volunteering. Despite the uncertainty around those figures, it is clear that the health benefits of volunteering account for large numbers and more should be done to improve their consideration for accounting purposes.

4.2.3.3 Accounting for spatial heterogeneity

Spatial aspects have received only limited attention in natural capital accounting. Some of the reviewed studies have provided maps of the spatial distribution of the different natural capital assets or ecosystem goods and services provided by a given area, but have generally not considered the effect of spatial aspects on the economic values. Whilst, in some cases, the value of the flow of ecosystem services is likely to be insensitive to the spatial configuration of natural capital, in many other cases, there may be important spatial elements to account for (Schaafsma, 2015)[48]. For example, the benefits of climate regulation are expected to be insensitive to the location where carbon is sequestered (regardless of where carbon is sequestered, the related benefits in terms of climate regulation services will be experienced by population around the world). On the other hand, people might for example experience different recreational benefits depending on where recreational opportunities are provided (e.g. closer or far away from home, in a certain habitat (e.g. woodlands) rather than others (e.g. coastal paths).

[45] Casiday, R., Kinsman, E., Fisher, C., Bambra, C. (2008). Volunteering and Health. What impact does it really have? Project report. Volunteering England.

[46] For further details see http://neweconomymanchester.com/stories/832-unit_cost_database

[47] Haldane, A. (2014). In giving, how much do we receive? The social value of volunteering. A Pro Bono Economics lecture to the Society of Business Economists, London

[48] Schaafsma M. (2015) Spatial and Geographical Aspects of Benefit Transfer. In: Johnston R., Rolfe J., Rosenberger R., Brouwer R. (eds) Benefit Transfer of Environmental and Resource Values. The Economics of Non-Market Goods and Resources, vol 14. Springer, Dordrecht

Based on the literature, the key spatial issues to consider when applying economic valuation methods for natural capital accounting purposes include:

- Distance (distance-decay)

The valuation literature has found evidence that the distance between the ecosystem good/service and the beneficiary plays an important role in determining how valuable a good or service is to the person. Based on the distance-decay paradigm, people's willingness to pay is assumed to diminish linearly as a function of the distance separating respondents from a given environmental resource of interest (Johnston et al., 2015)[49]. While distance is probably the most well-known spatial driver of values, many other factors are though also expected to drive spatial heterogeneity of individuals' preferences.

- Substitutes/complements

In addition to distance, another spatial factor that is expected to play a role is the availability of "substitute" and "complement" ecosystem goods and services. Substitutes refer to those ecosystem goods or services that are perceived to provide the same level of wellbeing, compared to another specific good or service of interest. For example, a broadleaved woodland can be viewed as a substitute for mixed forests by recreationists if visitors are indifferent to the woodland type when choosing the location for their trip. Complements, on the other hand, are those ecosystem goods or services that provide more wellbeing to people when consumed jointly with something else. For example, the value of an urban greenspace is higher when a pond is also present. Ignoring the existence of substitute or complements for given ecosystem goods and services of interest affects the measurement of the values that people obtain from the environment. Based on the above, when substitutes are overlooked the economic value of a given ecosystem good/service should be over-estimated, while the reverse should be true when complements are ignored.

- Distance and substitutes/complements effects

The effect of distance can be mediated by the availability of substitutes/complements, such that it does not only matter how far individuals are from a given environmental good, but also how this distance relates to the location of other substitute/complement sites (Schaafsma et al., 2012; 2013)[50]. In this case, distance-decay effects also depend on the geographical distribution of substitute or complement sites.

- Type of habitat and endowment

---

[49] Johnston, R.J. & Ramachandran, M. Environ Resource Econ (2015). Modeling Spatial Patchiness and Hot Spots in Stated Preference Willingness to Pay 59 (3): 363-387.

[50] Schaafsma, Marije, Brouwer, R., Rose, J. (2012) "Directional Heterogeneity in WTP Models for Environmental Valuation." *Ecological Economics* 79: 21–31.

Schaafsma, M., Brouwer, R., Gilbert, A., van der Bergh, J., Wagtendonk, A. (2011). Estimation of Distance-Decay Functions to Account for Substitution and Spatial Heterogeneity in Stated Preference Research. Land Economics 89(3): 514-537.

The value of ecosystem services has been proved to differ depending on the habitats or ecosystems supplying them (Christie et al., 2011[51]; Interis and Petrolia, 2016[52]). For example, individuals may have preferences regarding which habitats to visit for recreational reasons, e.g. prefer a recreational visit to coastal areas than to intensive grasslands.

Similarly, the value of a good or service depends on how of it much there is already available. For instance, an extra unit of an already abundant good in a given area should be valued less compared to an extra unit of a relatively scarce good (Sagebiel et al., 2017[53]; Bateman et al., 2011[54]).

- Similarity of the socio-economic context

The characteristics of the population of beneficiaries are also important and can contribute to spatially-defined effects. For example, differences in income across beneficiaries, with higher-income respondents displaying higher willingness to pay (Bateman et al., 2011[55]), are likely to be spatially heterogeneous.

To illustrate the above points, in box 11 below, we test for the role of spatial factors on recreational values.

Box 11. Testing the role of spatial factors on recreational values

To monetise the value of recreational visits, the reviewed natural capital accounts have commonly relied on the results of the meta-analysis regression estimated by Sen et al. (2014)[56], which considers around 300 UK valuation studies focusing on recreation. The Sen et al. (2014) meta-analysis specifically controls for information on the visited habitat type. The study provides information on the recreational value (per person and per trip) of visiting a woodland or forest; enclosed farmland; semi-natural grassland; a river, lake or canal; mountain, hill or moorland; and coastal margins. However, no other spatial factor (among those mentioned above) is accounted for in the Sen et al. (2014) meta-analysis. An improvement in this sense is offered by considering the recreational value estimates provided by the Outdoor Recreation Valuation (ORVal) Tool (https://www.leep.exeter.ac.uk/orval/), developed by researchers at the University of Exeter and focusing on the calculation of the welfare value of a recreational day visits to greenspaces in England and Wales.

[51] Christie, M., Hyde, T., Cooper, R., Fazey, I., Dennis, P., Warren, J., Colombo, S., Hanley, N. (2011). Economic Valuation of the Benefits of Ecosystem Services delivered by the UK Biodiversity Action Plan. Final Report to Defra
[52] Interis, M., Petrolia, D.R. (2016). Location, location, habitat: How the value of ecosystem services varies across locations and by habitat. Land Economics 92: 292-307.
[53] Sagebiel, J., Glenk, K. and Meyerhoff, J. (2017) Spatially explicit demand for afforestation. Forest Policy and Economics, 78, pp.190-199.
[54] Bateman, I., Brouwer, R., Ferrini, S., Schaafsma, M., Barton, D.N., Dubgaard, A., et al. (2011). Making benefit transfer work: deriving and testing principles for value transfer for similar and dissimilar sites using a case study of the non-market benefits of water quality improvements across Europe. Environmental and Resource Economics. 50(3): 365-387.
[55] Bateman, I., Brouwer, R., Ferrini, S., Schaafsma, M., Barton, D.N., Dubgaard, A., et al. (2011). Making benefit transfer work: deriving and testing principles for value transfer for similar and dissimilar sites using a case study of the non-market benefits of water quality improvements across Europe. Environmental and Resource Economics. 50(3): 365-387.
[56] Sen. A., Harwood, A.R., Bateman, I.J., Munday, P., Crowe, A., Brander, L., et al. (2014). Economic Assessment of the Recreational Value of Ecosystems: Methodological development and National and local application. Environmental and Resource Economics 57(2): 233-249.

The published literature acknowledges that sites with similar land cover types can be valued differently depending on the accessibility of such locations and the distance that recreationists have to travel to visit those sites. Locations which are more accessible to people tend to be valued more, and people willing to travel a longer distance to visit a particular site are placing a greater value on the visit. These aspects, overlooked in the Sen et al. (2014) meta-analysis regression, are accounted for in the ORVal tool. In the calculation of the welfare measures, ORVal accounts for heterogeneity in the accessibility of different sites and considers the distance travelled by visitors to reach the destination from their place of residence (as well as incorporating the use of different modes of transport, i.e. car versus walking).

In addition to accounting for habitat-specific differences in recreational values, the ORVal model also employs a flexible econometric specification which controls for the availability of substitute sites that individuals could have considered for their visit (i.e. the degree of similarity between types of recreational sites). Respondents may for example consider recreational paths as being more similar to each other than to other types of recreational sites, such as parks. In addition, it can be expected that greenspaces with similar land covers, e.g. two woodlands, are perceived as closer substitutes than recreational sites with different habitats, e.g. a woodland and a moorland. It is also assumed that sites which can be reached by the same mode of transport are perceived as being more similar (e.g. two parks within walking distance) compared to two sites that need to be accessed using a different mode of transport (e.g. a local neighbourhood park vs a park that is driving distance away). The underlying idea in the model is to allow respondents to place a greater value on visiting unique sites with fewer alternative/substitutes locations available. Accounting for alternative substitute and complement sites has been acknowledged to play an important role to estimate more accurate values. However, this is not something that is generally incorporated into standard practice Natural Capital Accounting, due to the challenges related to the incorporation of such complex spatial patterns into the valuation analysis.

To illustrate the importance of accounting for spatial factors (beyond habitat-specific differences), we have calculated and compared the recreational values of Dartmoor and Exmoor National Parks using the Sen et al. (2014) and the alternative ORVal-based approaches. The ORVal figures for Dartmoor and Exmoor where taken from the online version of the tool, available at: https://www.leep.exeter.ac.uk/orval/.

	Sen et al. (2014) estimates	**ORVal estimates**
Dartmoor National Park	£15,516,528	£20,260,274
Exmoor National Park	£2,762,899	£8,023,928

From the above comparison, it emerges that the Sen et al. (2014) approach appears to undervalue the recreational values of both Dartmoor and Exmoor National Parks. Differences, though, could be driven by a variety of factors, which we will discuss below with the help of a series of illustrative case studies.

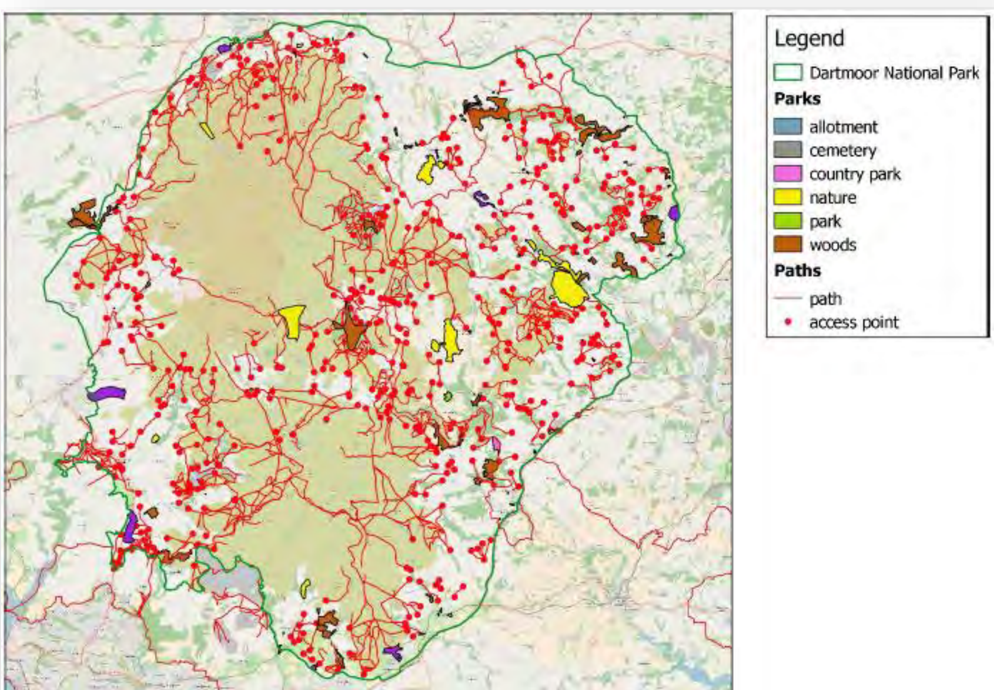
The first difference that can be detected across the two studies concerns the estimates of values per habitat. As described earlier, ORVal provides more accurate estimates of recreational values by considering a more behaviourally realistic model of recreational demand which accounts for distance, location and the availability of substitute sites, as recommended by the literature. Recreational values per habitat in ORVal are estimated by assuming that a visit to a given habitat site is not constant (as assumed by the Sen et al. (2014) meta-analysis), but can vary depending on the distance of the site from the recreationist and the availability of alternative sites with similar characteristics. Compared to the Sen et al. (2014) study, the ORVal model tends to estimate higher values per visits for most of the habitat classes considered. Based on the table provided below, this means that some habitats (i.e. woodlands and mountains, moors and heathlands) tend to be overvalued when using the “standard practice” approach based on the Sen et al. (2014) estimates of recreational values, whilst others (i.e. freshwater ecosystems, natural and semi-natural grassland and farmland habitats) tend to be undervalued.

Value per visit per habitat: comparing the standard practice with a more sophisticated approach

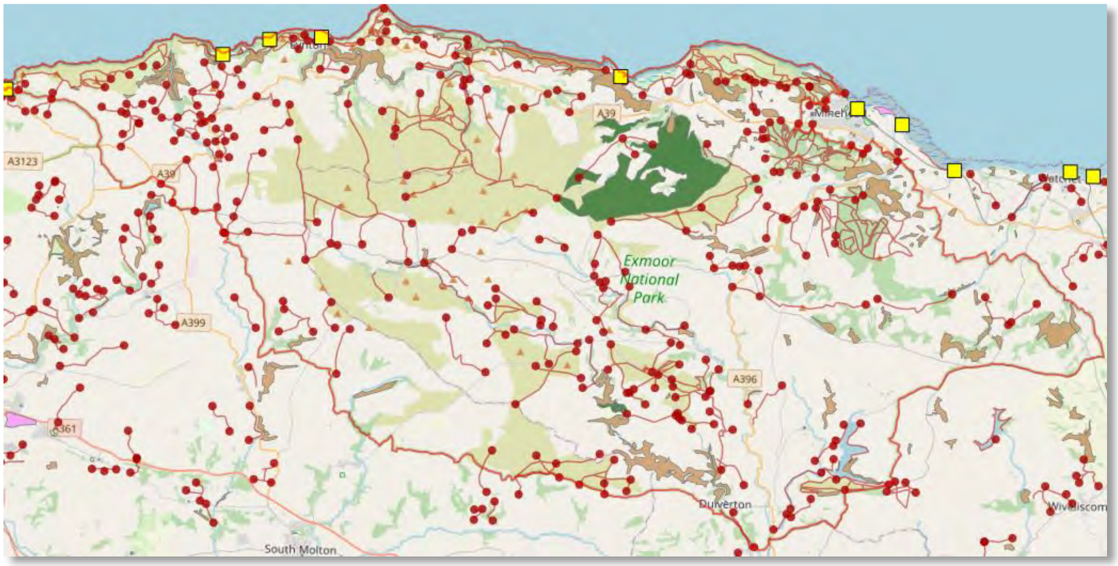
	Sen et al. (2014) 2015 prices	ORVal model 2015 prices
Woodlands	£ 3.61	£ 2.99
River, lake or canal	£ 1.96	£ 3.67
Mountains, moors heathlands	£ 5.44	£ 4.55
Semi-natural grassland (Sen) Natural grassland (ORVal) Managed grassland (ORVal)	£ 1.67	 £ 3.42 £ 2.78
Enclosed farmland (Sen) Agriculture (ORVal)	£ 1.67	 £2.78
Graveyards and cemeteries		£ 3.36
Allotments		£6.24

The second effect of spatial aspects that we want to illustrate here, is that recreational values are also sensitive to accessibility. Recreational values are likely higher in locations with more access points. For this reason, the assumption of homogeneous visitation rates across the area of interest that is assumed in "standard practice" natural capital accounts is often not realistic. Based on the ORVal map of access points for Dartmoor and Exmoor shown below, for instance, it is clear that some areas of the National Parks are more accessible than others, and, as illustrated for Dartmoor, some areas are visited more heavily than others. Therefore, assuming homogeneous visitation rates can substantially misrepresent the recreational values of certain portions of the National Park, with important implications in terms of spatial planning and decision-making.

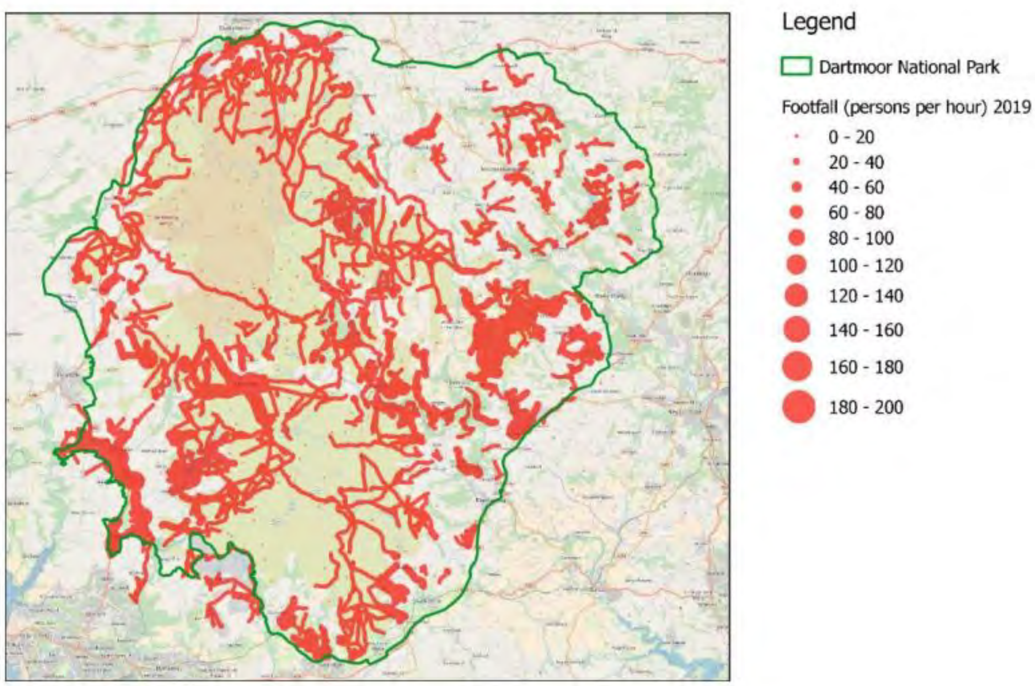
Dartmoor access points



Exmoor access points

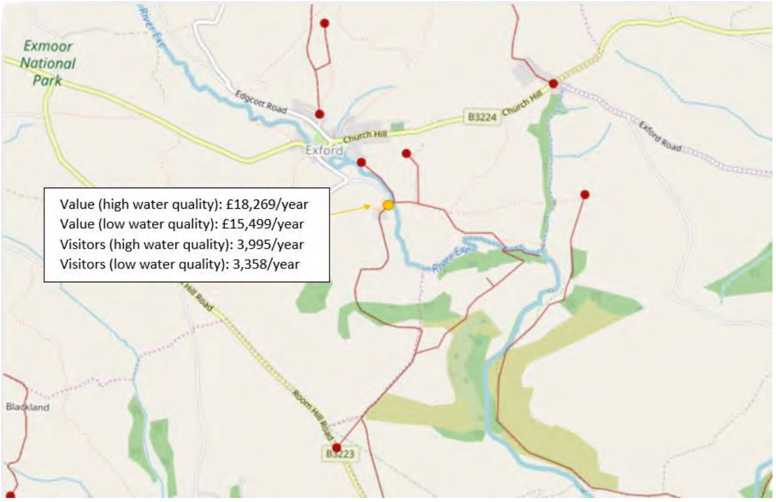


Dartmoor visitation hotspots



To understand how accessibility of sites can affect values and management decision making, we here give a hypothetical example for woodland creation. Creating a new woodland will create additional opportunities for recreation and we want to test how recreational values are affected by different degrees of accessibility. We simulate the creation of a new broadleaved forest of 20 hectares north of Princetown in Dartmoor National Park. In the map illustrated below, the yellow dot is the location where the woodland creation was originally proposed. ORVal then provides information on the welfare value and number of visits not only for the proposed new woodland site (yellow dot), but also for alternative nearby locations (11 purple dots). Larger dots indicate a larger recreational value. As the map illustrates (through the relative size of the purple dots), the recreational benefits associated with such broadleaved woodland creation are greater the closer the site is to accessible areas (in this example, the location with the largest value is the point located closest to the road network and access points from Princetown). The highest value (£136,296/year) and visitation rate (41,525/year) would be associated with placing the woodland close to Princetown. However, creating a new woodland close to an already existing woodland is associated with lower welfare benefits (£39,576/year) and visitation rates (12,485/year), even if the woodland is located close to an accessible location. The implication of the above is that if a constant recreational value is assumed for all sites, it is likely that recreational areas that are more attractive for visitors are undervalued, whilst areas which are of less importance for recreationists are overvalued. Such information has important implications for decision-making and planning, as not considering spatial effects would likely lead to suboptimal amounts of habitat creation efforts being implemented in areas that are potentially more valuable for recreationists.

Lastly, we illustrate the role of spatial variation in ecological features on the economic value of recreational visits. We consider the effect of a change in the water quality of a river in an area with recreational interest; looking at a decrease from high to low water quality in the River Exe close to Exford in Exmoor National Park.



The 2016 value associated with visiting a location placed closed to the river is £18,269/year and the number of annual visits accounts for 3,995/year. Under the assumption that water quality went down from high to low, the same recreation site would experience a decrease by £2,770 (per year) in terms of recreation values and a decrease by 637 estimated visits (per year). This example illustrates that the quality (or condition) of the natural capital has a significant effect on the estimation of the economic value of greenspace. This is because for recreationists, a degradation in the condition of the natural environment (in this case water quality) negatively affects their visitors' experience (hence, why the reduction in value). Overlooking the role of the ecological condition of the site on the recreational experience of visitors (as in the standard practice approach to natural capital accounting) can provide very different results with implications for decision-making and planning. Recreational values might be substantially undervalued if the valuation process ignored the fact that the ecological condition (e.g. water quality) at the visited site is high, while the reverse would be true if degraded ecological conditions were overlooked and instead assumed to be average or higher. Taking these factors into account in the valuation is essential to ensure that natural capital results can informatively underpin environmental policies regarding the maintenance or improvement of habitat condition.

4.2.3.4 Accounting for aspects related to temporal dynamics

Natural capital accounting focuses on recording information on natural capital assets, ecosystem goods/services and the related monetised values at a given point in time, and monitoring how these change over time. Indeed, time is a crucial dimension. To account for temporal issues, the reviewed natural capital accounts have tended to present flow accounts, showing the value of the ecosystem goods and services provided for one year of reference, as well as stock accounts, by calculating the net present value of the flow of ecosystem goods and services that the natural assets are expected to provide over a period of time into the future. With this respect, as described in sub-section 4.2.2.5, a first assumption that needs to be made concerns the length of time over which an asset is expected to provide goods and services. Another decision that needs to be taken at this stage concerns the most appropriate discount rate for the calculation of the net present value. A discount rate reduces the value of a good or service that is delivered later in the future. The idea is that a good is more valuable if it can be enjoyed in the present, while it is valued less if it can be enjoyed only at a later stage. If we think about money, £10 earned today are preferred to £10 earned in a year's time, £10 earned in a year's time are therefore worth less. Following the above reasoning, for example, a woodland planted this year and providing recreational opportunities should be valued more (providing more happiness or utility in economic terms) than the same woodland planted at a later time. Following this logic, discount rates are typically numbers bigger than zero. However, the higher the number the more the future is discounted in favour of present generations and at the expense of future generations. It is acknowledged that environmental goods and services should not be discounted following the same rates as financial markets. The Government periodically issues recommendations regarding the most appropriate discount rates to use for environmental goods and services. However, the debate around which discount rate is the most appropriate is still ongoing, and several alternative choices of discount rates are available. In box 12, we explore the use of alternative assumptions regarding discount rates.

Box 12. Alternative assumptions regarding the discount rate

Generally, the guidelines for discounting the flow of environmental goods and services that are produced over time rely on the Government guidelines as set in the HM Green Book document. Recommendations are generally that a discount rate of 3.5% is employed for flows projected out to 30 years, with discount rates declining to 3% for longer periods of time. This decline (to the so called 'reduced' discount rate) is justified by the fact that for significantly long periods into the future (i.e. exceeding 30 years) it is not ethically defensible not to employ a lower discount rate, given the irreversible wealth transfers that is otherwise implied from the future generations to the present generation. The table below summarizes various long-term discount rates that the Green Book considers for different ranges of time:

Period of years	0-30	31-75	76-125	126-200	201-300	301+
Standard rate as published in the Green Book	3.5%	3.00%	2.50%	2.00%	1.50%	1.00%
Reduced rate where 'pure STP' = 0	3.00%	2.57%	2.14%	1.71%	1.29%	0.86%

Alternative discount rates for the valuation of the flows of environmental goods and services taking place in the very long term are recommended elsewhere (e.g. Drupp et al. 2018)[57]. Drupp et al. (2018) report the results of a survey to a poll of experts who were asked about acceptable estimates of the social discount rate for very long-term environmental problems. The median value estimated from this exercise was 2%, ranging from a lower bound of 1% to an upper bound of 3.5%. The minimum value provided in the survey was 0% and the maximum was 10%. This shows that there can be huge variation in the figures that we can considered for the social discount rate.

To illustrate the sensitivity of the account values to the choice of the discount rate we consider the case of carbon sequestration as an example. As set out in the Defra/ONS (2014) document[58] focusing on principles of ecosystem accounting, the time period for valuing timber production is assumed to be 50 years and, as such, the asset value of other woodland-related services (including carbon sequestration) should also be capitalised over the same period of time.

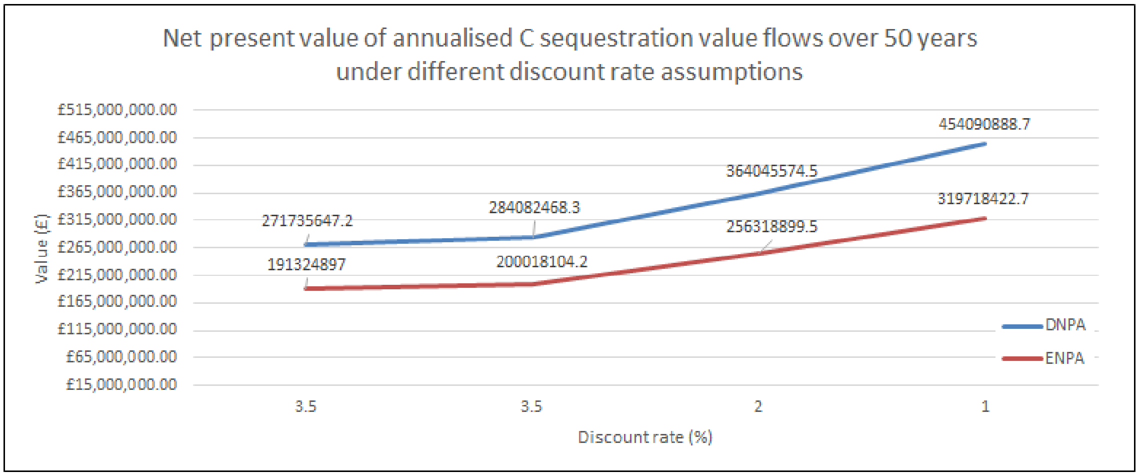
Below we compare the value of the flow of carbon sequestration services over the assumed period of time (50 years) for Dartmoor and Exmoor, by considering different discount rates, to show how sensitive results are to the choice of the discount rate:

[57] Drupp, M., Freeman, M., Groom, B, Nesje, F. (2015). Discounting disentangled: an expert survey on the determinants of the long-term social discount rate. Centre for Climate Change Economics and Policy working paper no. 195 https://www.cccep.ac.uk/wp-content/uploads/2015/10/Working-Paper-172-Drupp-et-al.pdf

[58] Defra/ONS (2014), Principles of ecosystem accounting. Paper for Natural Capital Accounting Steering Group.

	Discount rate			
	3.5%	HM 3.5% + 3%	2%	1%
Dartmoor National Park	£271,735,647.16	£284,082,468.36	£364,045,574.53	£454,090,888.69
Exmoor National Park	£191,324,896.96	£200,018,104.19	£256,318,899.51	£319,718,422.66

Results of this exercise (reported in the above table and the figure below) show that the total net present value figures for the annualised flows of carbon sequestration values vary considerably depending on the discount rate, with much higher net present values calculated when lower discount rates are considered.



4.2.3.5 Testing for the effects of using alternative economic value estimates

The reviewed "standard practice" natural capital accounts have shown, in some cases, consistency in the use of approaches and values to quantify the economic benefits provided by specific goods and services. This has been the case, for instance, for the valuation of carbon regulation services and recreation, which have consistently relied on the abatement cost approach for the former and the values estimated from the Sen et al. (2014) meta-analysis for the latter (as illustrated in Appendix 6).

However, for some ecosystem goods and services the reviewed natural capital accounting studies have employed different/alternative valuation approaches and figures. The availability of multiple valuation options raises the question of which approach is most appropriate for the purposes of compiling a natural capital account, and should therefore be selected. Sometimes the choice of one approach over another is justified by strong arguments (i.e. alignment with the accounting principles as set out in the System of Experimental Environmental Accounts (SEEA)). However, in some other cases, it is less clear what valuation approach should be favoured.

In most of the reviewed examples of natural capital accounts developed for protected areas or organisations with an environmental remit, the "standard practice" methodology employs economic values that proceed from national statistics or generic literature reviews. In some cases, such national or generic values can be appropriate, for example, in the case of carbon sequestration values, which should be the same regardless of the specific settings. However, in other circumstances this is not the case and local knowledge and expertise can be important in identifying which valuation approach is most appropriate in the development of a robust Natural Capital Account. In Box 13 below, we illustrate the implications of using local knowledge to inform the most appropriate value estimates for crops.

Box 13. Testing alternative assumptions using local knowledge: crop values

In the reviewed natural capital accounts, the most frequent approach to value the benefits from agricultural crop production is based on the consideration of resource rents or farm gross margins. One useful reference source for this purpose is the John Nix Pocketbook for farm management 2018 (Redman 2017)[59]. For certain crops (i.e. wheat and barley) different values are presented depending on the final use of the crops (whether the crops are primarily used for human-related consumption (e.g. milling or malting activities) or whether they are primarily used for animal feeding).

In the draft account for Dartmoor National Park, it was naively assumed that all produced wheat and barley is used for human-related consumption. However, stakeholder consultation and local knowledge of the farming system on Dartmoor, revealed that most of the wheat and barley produced on Dartmoor (2,687 tonnes/year for barley and 7,804 tonnes/year for wheat) is used for animal feed. Based on this, the figures used for crop valuation were edited (to reflect feeding rather than milling/malting prices – as reported in the table below):

	Malting and milling prices (2015£/tonne)	**Feed prices (2015£/tonne)**
Barley	82	72
Wheat	80	82

The total value of agricultural production (including all crops, not just wheat and barley) before and after the above change is summarised below. Feed price for barley is smaller than the malting and milling price, while the reverse is true for wheat prices. Overall, it is possible to observe a decrease in the value of agricultural crop production in the accounts when moving from malting/milling to feed prices for the two selected crops. Without introducing the above-mentioned adjustments, informed by local knowledge and expertise, the conclusions of the accounts wouldn't have dramatically changed, but crop values would have been overestimated.

	Malting and milling prices	**Feed prices**
Total value of agricultural crop production on Dartmoor for 2015	£1,286,865.37	£1,285,825.53

[59] Redman, G. (2017). The John Nix Pocketbook for Farm Management 2018. 48th Edition. Melton Mowbray: Agro Business Consultants

4.3 DISCUSSION OF THE USEFULNESS OF "STANDARD PRACTICE" ACCOUNTS

Upon completion of the accounts, following the "standard practice" approaches, we discussed with the National Park Authorities the usefulness of the produced natural capital accounting to inform their decision-making. The discussion was guided by the list of aspirations identified by Dartmoor and Exmoor staff in a meeting at the beginning of the project (see step 1 of the methodology section).

The table below reports the main aspirations identified by the National Park Authorities' staff at the start of the project. A colour code was assigned to each aspiration at the end of the project to indicate whether the produced Natural Capital Accounts were perceived to meet the initial aspirations and are useful for decision-making. Green indicates that initial aspirations were met; orange that aspirations were only partially met and red that aspirations could not be met.

	Exmoor National Park	**Dartmoor National Park**	
	Provide improved information to feed into the State of the Park report	Provide improved information to feed into the State of the Park report	
	Provide input into the Environment Land Management Schemes (ELMS)/payment for farming, e.g. by putting value on provided ecosystem services	Explore the use of Natural Capital accounting for investment decision-making, e.g. when needing to prioritise between choice of two management/restoration options	
	Land ownership/land holdings: understand best use for land owned by Exmoor National Park	Leveraging funding/justifying spending. Understanding the monetary value resulting from e.g. a restoration project, and use this knowledge to leverage money for cost of project	
	Use to show where (data) gaps are in decision-making	Influencing management decision-making, e.g. increasing amounts of stocks which are shown to have high value	

As shown by the colour-coding in the above table, it was perceived that, in most cases (red boxes), "the standard practice" natural capital accounting could not satisfy initial expectations. Both National Park Authorities felt that current approaches in "standard practice" natural capital accounting are only of limited usefulness to inform decision-making. It was highlighted that the accounts can be useful to provide some improved information to feed into the State of the Park report (a document which all National Park Authorities are required to prepare, providing a non-technical overview of the status and trends of a park's natural resources and highlighting possible issues and challenges for the future). At present, no standard and rigorous methodology is employed for the preparation of such reports. It was felt that the natural capital accounting framework presented as part of this project could provide improved structured information on the Natural Capital stocks, ecosystem services and value flows for the State of the Park reports. It was also felt that the project was helpful to identify knowledge gaps and data shortages (amber box).

It was concluded that the remaining aspirations could not be met using Natural Capital Accounting (red boxes). Dartmoor and Exmoor National Park Authority staff felt that the information from the accounts could not be used to help influence management decision-making. The gaps in the account and the illustrated sensitivity to the underpinning data were perceived to be a major barrier to the employment of the account results to guide management decisions. It was also concluded that the produced accounts could not guide Exmoor's decisions regarding the best use of NPA-owned land and the design of farming payment schemes. This is due to a scale issue; accounts covering the full National Park area are not helpful to inform decisions concerning, for example, specific farms or NPA-owned parcels of land. Finally, the National Park Authorities concluded that the accounts could not be used for leveraging and justifying spending, or to inform investment decision-making. Natural Capital Accounts are not designed specifically with these purposes in mind, and the fact that these ambitions were outlined but not met, may represent a mismatch between the actual uses and applications of Natural Capital Accounts, and the perceptions of organisations regarding what Natural Capital Accounts can be used for.

While it was felt that the underlying idea behind natural capital accounting could prove useful, there has been a consensus that Natural Capital Accounting is still in its early days, and that the methodology and framework need to be improved substantially before the approach can become useful to inform management decision-making for environmentally-facing organisations such as National Parks. Whilst developing Natural Capital Accounts at organisational level is increasingly encouraged by the Government, there are still considerable gaps in relation to how accounts can be implemented in a way which is useful for decision-making. In the specific case of National Park Authorities, the development of natural capital accounts for the whole parks' area has limited direct management relevance, as these organisations do not have ownership or management control over all land within the National Park boundaries. Therefore, a Natural Capital Account for an organisation such as a National Park Authority will, by definition, have limited management usefulness, as decision-making on the natural capital assets and land-use is not always within the organisation's control. One possible solution would be to create accounts focused exclusively on the Natural Capital owned or managed by the National Park Authorities, but this would mean that the full benefits flowing from the UK's National Parks are not adequately captured as many areas would be excluded from the account.

One of the major concerns raised by stakeholders was regarding the reliability of the Natural Capital Accounting approach and the resulting total value estimates. As shown in section 4.2., account results are highly sensitive to the underpinning data sources used to measure natural assets, flows of ecosystem goods and services and values. Such variability makes current standard practice for Natural Capital Accounting at an organizational scale an unreliable instrument for decision-making. Based on discussions with Dartmoor and Exmoor National Park Authority representatives, it was clear that Natural Capital Accounting can only be as good as the underlying data employed in the process. If, as we have shown, the underlying data are subject to limitations and are inaccurate or incomplete at the spatial scale of interest, natural capital accounting will misrepresent the value of the natural environment. For these smaller-scale, organisational Natural Capital Accounts to be informative in the future, more support is needed to supply or collect fit-for-purpose data. This includes in particular repeatable high-resolution land cover datasets for vegetation categories of management interest, as well as comprehensive, National Park-wide data on, for example, ecosystem condition, livestock numbers, water extraction and other measures needed to quantify ecosystem service flows.

In addition, ensuring consistency in the accounting methodology used by different organisations with similar characteristics is essential for comparison purposes. One additional suggestion going forward is to agree on a standard selection of datasets that all National Park Authorities should hold and monitor over time (in addition to any other organisation-specific data and monitoring). This would be helpful to address existing concerns about the repeatability of the accounting process over time, which is now difficult due to the patchiness of data available.

The review of standard practice revealed that Natural Capital Accounts are often skewed in favour of private (or market-based) goods and only partially include public (or non-market) goods. In the case of organisations such as National Park Authorities, whose remit is to ensure a sustainable use and appropriate conservation of the natural environment, the exclusion of important environmental public goods from the accounts is one of the biggest limitations of Natural Capital Accounting in its present format. This is particularly true in relation to ecosystem goods and services such as biodiversity, wildlife, landscapes and cultural heritage, upon which National Park Authorities focus much of their management efforts. The fact that current "standard practice" cannot value these goods and services means that National Park Authorities cannot appropriately compare the value of these ecosystem services (of key organisational importance) with those of other ecosystem services produced by the National Park. This is a severe limitation for the management usefulness of the Natural Capital Approach. It also means that the accounts cannot be used to provide evidence on the full value of management interventions implemented to benefit biodiversity (for example, increasing habitat extents of known biodiverse habitat sites). This is a major limitation also when it comes to justifying the request for extra funding. It was hoped that the Natural Capital Accounts could be used to help make the case for additional investment in the natural environment. However, what emerged from the conversations with the National Park Authorities is that, compared to existing knowledge, information from the "standard practice" Natural Capital Accounts provides less leverage than originally hoped to justify funding requests.

The standard approach adopted by practitioners to produce Natural Capital Accounts is also of limited relevance for building an understanding of specific local issues. For example, one of the aspirations initially identified by Exmoor National Park Authority was to use Natural Capital Accounts to better understand the various benefits and impacts of farming for separate land holdings and ownership types. This is not an issue generally addressed by "standard practice" Natural Capital Accounts, revealing a possible mismatch between organisations' expectations and the actual capabilities of "standard practice" Natural Capital Accounts. Whilst in theory (see section 2.2), Natural Capital Accounts could be further customised to present results by groups of users or beneficiaries of interest to reflect specific management issues, this is rarely done in practice. Another topic of interest, which "standard practice" Natural Capital Accounts fail to address, is related to the role of a range of ecosystem services that are very specific to the local area, but often of substantial cultural value. These include, for example, the importance of: i) bees and heather, contributing to local heather honey production, and ii) Dartmoor and Exmoor ponies, which are unique and charismatic species, contributing to the recreational enjoyment of the area and to conservation grazing. These values are not captured using the "standard practice" approach in Natural Capital Accounting. Further understanding of the above benefits would therefore require comprehensive, National Park-wide data, resources and expertise to go beyond the "standard practice" approach and create tailored Natural Capital Accounts which better meet the organisation's expectations.

We can conclude that whilst there are broad expectations regarding what a Natural Capital Account can and cannot do, the current "standard practice" Natural Capital Accounts do not deliver the management tool which both our case study organisations (DNPA and ENPA) may need. From discussions with the National Park Authorities, a common theme was related to the perceived complexities and challenges associated with Natural Capital Accounting for environmental organisations. Frequent concerns raised were in relation to the limited time, resources and expertise that National Park Authorities would have in-house to design and maintain natural capital accounts, which may limit the feasibility and uptake of this approach. Based on discussions with the National Park Authorities it was felt that perhaps Natural Capital Accounting is not the most useful approach to inform decision-making. When specific management questions arise, for examples when organisations are faced with the choice between alternative management or investment decisions, a cost-benefit analysis could be a more appropriate tool. This approach provides a side-by-side comparison of the total costs and benefits (in monetary terms) of alternative options, which is something a Natural Capital Account cannot provide. An additional approach which could be considered is the development of a risk register of natural capital assets. A risk register identifies the risk of changes to the assets (i.e. habitat quality) and delivery of ecosystem services, and could be more informative than an annual Natural Capital Account to understand which natural assets are in need of management changes or additional protection. However, it is important to acknowledge that both of the above approaches (cost benefit analysis and risk registers) can suffer from similar methodological issues and data shortages as Natural Capital Accounts. These alternative options are therefore likely only appropriate in specific instances, such as smaller case studies, when the management question, staff expertise and data availability allow the application of such approaches.

5 LESSONS LEARNT AND RECOMMENDATIONS

Based on the insights gathered through this project, there are a number of valuable lessons learnt and recommendations that we believe can help practitioners, policymakers and organisations in the development of more useful Natural Capital Accounts.

1. **More clarity is needed about what a Natural Capital Account is and what it is not.** Whilst there is a general understanding that "natural capital thinking" is about placing the environment (and the related benefits to people) at the heart of decision-making, several misconceptions regarding Natural Capital Accounting still exist. The stakeholder consultations in our project revealed that more clarity is needed on the underlying principles and methods, as well as the types of questions that Natural Capital Accounting can feasibly answer. Natural Capital Accounts are designed to monitor changes in natural capital stocks, ecosystem services and values over time. They can be helpful to identify priority (valuable) habitats and can evidence and communicate the value of nature when areas are considered for human development (e.g. housing or infrastructure). They are, however, not a tailored decision-making tool to answer all the wide-ranging management questions faced by environmentally facing organisations. National Park-wide accounts alone will generally not provide answers regarding the optimal use of smaller parcels of land or help select the optimal management or restoration options. There is a need for more awareness regarding the capabilities and potential applications of this approach, particularly in the context of management decision-making. Based on discussions with the National Park Authorities, it emerged that Natural Capital Accounts are often mistakenly perceived as project appraisal tools to support decisions regarding alternative investment options. This raises the question of whether alternative decision-support approaches (such as cost-benefit analyses or Natural Capital risk registers) could represent more useful tools to guide management decisions of organisations with an environment remit. The results of stakeholders' discussions held within our project, have highlighted that, whilst providing a useful overview of the National Parks' natural capital and the related key ecosystem services, in its present form, the Natural Capital Accounting approach is only of limited wider management usefulness to National Park Authorities. The production of Natural Capital Accounts for only those areas where National Park Authorities have management control (as opposed to the whole National Park area), may help improve the management usefulness of Natural Capital Accounts. This may mean that the accounts can be more informatively used to, for example, monitor the effects of land management interventions. However, the limitations regarding the underpinning data and estimates, as outlined in this report, would still be an issue that would need to be taken into consideration regardless of the approach considered.

2. **Guidelines are needed to support the development of Natural Capital Accounts for local and regional scales**. Alongside clarifying what a Natural Capital Account is and is not, more recommendations are needed on the practical steps that need to be followed in order to implement Natural Capital Accounting. Step-by-step guidelines for the development of local Natural Capital Accounts are currently not available but encouraged by the Natural Capital Committee. Clear guidance on the methodology would prevent different environmental organisations using different approaches and it would be beneficial for the development of a consistent and robust approach across organisations, which would be useful for comparability purposes.

3. **Tools for natural capital assessment and monitoring, ecosystem service quantification and valuation are needed to support the development of Natural Capital Accounts and collaborations with experts should be encouraged.** Based on our stakeholder discussions, Natural Capital Accounting was perceived as an onerous task. Overall, it was felt that the development of Natural Capital Accounts for organisations such as Dartmoor and Exmoor National Park Authorities is challenging due to the limited availability of both resources and expertise to develop and update the accounts. Whilst this report focused on the entire National Park area, the same limitations would be present if smaller areas were considered (e.g. only the areas under National Park Authority ownership and management). Developing a Natural Capital Account can be highly time-consuming and requires interdisciplinary knowledge and a range of technical and analytical skills, often not available in-house. Publicly available tools, developed by academics or other specialists, but tailored for use by non-specialists, need to be encouraged to help support the development of Natural Capital Accounts. In this project, for example, we have used publicly available online tools such as ORVal and NEVO, which are sophisticated but user-friendly integrated valuation tools. Such tools can provide organisations with easily obtainable, scientifically underpinned estimates of ecosystem services and values to be used in the natural capital accounting process. If organisations don't have the necessary resources or skills to develop Natural Capital Account themselves, collaborations with specialists should be encouraged.

4. **Data availability is a major issue and fit-for-purpose data collection for Natural Capital Accounting should be promoted**. We showed in this study that when the underpinning data are subject to limitations, Natural Capital Accounts will misrepresent the values of the natural environment. Despite the availability of nation-wide information on some natural capital assets, ecosystem services and values, there is an overall lack of data to consistently and reliably measure natural assets over multiple years to detect change. Data on asset condition is also often not available across the entirety of the area of interest. In addition to this, data gaps also exist regarding the quantification of a range of ecosystem goods and services (e.g. flood protection or wildlife), which are of key importance to National Parks. With respect to the above, there is therefore a need to support National Park Authorities and similar

organisations with fit-for-purpose data collection for Natural Capital Accounting purposes. At a minimum, this should include multi-year data on assets across the whole of the National Park, as well as ecosystem service measures which cannot typically be derived from national data (e.g. water extraction, game harvesting and volunteer numbers). The frequency of data collection, and therefore of the accounts, depends on organisational interests, as well as the anticipated speed of environmental change. In addition, the collection of National Park-wide data on locally important assets (e.g. ancient woodland) or ecosystem services (e.g. Dartmoor/Exmoor pony numbers) should be promoted. Otherwise, there is a risk of overlooking or inappropriately accounting for such assets and services when national data are used. One promising opportunity to fill data gaps regarding natural assets lies in the use of remote sensing data (such as Sentinel data collected by the European Space Agency), which offer several advantages: the information is publicly available, collected regularly, and it allows for fine-scale detailed detection of changes in natural asset extent and potentially condition. Some specialist GIS expertise is needed to process remote sensing data into a useable land cover map. However, expert collaborations can be used to aid this process and open access tools are increasingly becoming available.

5. **Valuation methods need to be further progressed to be fit-for-purpose for Natural Capital Accounting**. Based on the results of our Natural Capital Accounts developed for Dartmoor and Exmoor, it emerged that the economic values of private goods provided by areas such as National Parks are relatively well represented, whilst some important public goods supplied are either completely or only partially included in the accounts. Importantly, no established methodology seems to be available to fully value the benefits of flood protection, cultural heritage, landscape values and biodiversity, which are crucial for organisations such as National Park Authorities. To include these and other currently overlooked goods and services into Natural Capital Accounts, more efforts are therefore needed to develop sound valuation methodologies.

6. **Uncertainties need to be made explicit**. Gaps in data and the limitations in the available methodologies need to be explicitly acknowledged when developing Natural Capital Accounting exercises, otherwise there is a risk of account results being open to misinterpretation. Sensitivity tests need to be more systematically performed in accounting exercises and the related estimates of uncertainties need to be reported. Narratives around the reliability of the results and any apparent gap or downsides in the approach need to be explained to ensure appropriate interpretation and use of the results.

7. **The quantification of the flow of ecosystem goods and services should be better linked to the ecological condition of natural assets.** Typically, the reviewed Natural Capital Accounting exercises have assumed that natural capital stocks supply constant rates of ecosystem goods and services. However, the capability of natural assets to provide goods and

services that benefit people heavily depends on the ecological condition of the stock. In this report, this is for example discussed in relation to the effect of water quality on recreation and the role of peatland condition on carbon sequestration. Wherever possible, data on asset condition, as well as evidence on the effects of condition on ecosystem service provision, should be included in the accounting process. However, data on asset condition across the entire area of interest is often lacking, and incorporating ecological condition would therefore often only be possible after extensive data collection efforts.

8. **The sustainability of extraction and/or use of natural capital stocks needs to be better considered.** Related to the above, the ecological condition of natural capital stocks also depends on the sustainability (or lack thereof) of resource extraction and natural capital stock use over time. Unless natural assets are sustainably managed, the assumption of constant flows of ecosystem services is inaccurate, as over-exploited natural capital stocks tend to supply declining rates of goods and services over time. For example, if the rate of logging in woodlands exceeds the rate of re-growth or plantation, a declining rate of timber production is to be expected. Better understanding of the implications of sustainable or unsustainable uses of natural capital stocks is crucial if Natural Capital Accounting is to be used to inform decision-making in the longer term. Flow accounts which only focus on annual ecosystem service supply (e.g. annual sequestration of carbon, annual timber extraction) only provide a partial picture and are often not sufficient to inform sustainable decision-making. Stock accounts, which measure the total ecosystem goods and services that are expected to be produced by a given natural capital until the end of its asset life, could instead be used to provide useful additional insights when there are sustainability concerns. Given that stock accounts provide a picture of the long-term availability of natural capital stocks and ecosystem goods and services, they can give an indication of the sustainability of natural resource use and extraction.

9. **Spatial aspects need to be better incorporated into Natural Capital Accounting**. Based on the reviewed Natural Capital Accounting approaches and wider literature, we can conclude that only limited consideration has been given so far to spatial aspects. No specific guidelines are available regarding whether Natural Capital Accounts should be spatially explicit and only a few case studies provided maps of the geographical distribution of natural assets or ecosystem services and goods. In this study, we have tested how spatial dimensions - including site accessibility, distance from the beneficiary, availability of substitutes and types of habitats – can affect the recreational values experienced by people. Given that for the majority of ecosystem goods and services, the location of the natural asset and the associated goods and services is important to drive economic values, spatially explicit natural capital accounting methodologies should be encouraged wherever possible, if decisions about spatial planning are to be made based on the results of the Natural Capital Accounting exercise.

10. **More consideration should be given to the costs of maintaining natural capital stocks for the provision of ecosystem goods and services**. In addition to considering the benefits and values of the ecosystem goods and services provided by natural assets, the costs that need to be incurred to support the provision of such goods and services, should also be taken into explicit consideration. These can include, for example, the costs of habitat management (e.g. woodland management), of provision of recreational opportunities (e.g. footpath maintenance and infrastructure for visitors) and of managing volunteering. Typically, cost accounts are not provided in the reviewed Natural Capital Accounts, but their inclusion could increase the management usefulness of the approach.

6 APPENDICES

Appendix 1. The general structure of an asset account (ONS-Defra, 2017)[60]

	Extent of ecosystem (area)	Volume (volume)	Biodiversity (indicator)	Soil (index)	Ecological condition (indicator)	Access (indicator)	Management practice (area)
Examples	Woodland, Freshwater	timber biomass; carbon stock; water quantity	Farmland Birds Index	carbon content, water content	water quality	proximity to areas of population	conservation status, organic farming
Opening stock							
Additions to stock[3]			Net change	Net change	Net change		
Reductions in stock							
Closing stock							

Source: Office for National Statistics

[60] ONS (2017). Principles of Natural Capital Accounting. A background paper for those wanting to understand the concepts and methodology underlying the UK Natural Capital accounts being developed by ONS and Defra. Available at: https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/principlesofnaturalcapitalaccounting

Appendix 2. List of ecosystem services to be considered in UK accounts (ONS 2017)[61]

Provisioning services

	Description of service	Notes
Biomass	Cultivated crops including horticulture (tonnes)	For example wheat; can include residues used as animal fodder.
	Grass (tonnes)	Livestock is excluded as the production of grass fodder is taken as the service.
	Wild fish (tonnes)	Aquaculture is treated in the same way as livestock.
	Woody biomass (cubic metres)	Production of timber
	Wild produce (tonnes)	Nuts, berries, mushrooms, wild animals
	Peat (tonnes)	For either horticulture or energy
Water (cubic metres)	Water (cubic metres)	Water abstracted, including groundwater and collected water Naviagation Possibly
Energy	Hydropower (joules)	Energy from hydropower
	Other renewable sources (joules)	Energy from wind, solar, tidal etc.

Source: Office for National Statistics

Regulating services

	Description of service	Notes
Mediation of wastes and nuisances	Air pollutant absorption by vegetation (tonnes)	Deposition of pollutants on bare soil is excluded
	Other waste remediation (tonnes /cubic metres)	Solid waste e.g. manure spreading
		Liquid waste e.g. effluent deposition/dilution /remediation (may be a supporting service to water provisioning)
	Noise mitigation (decibels)	Shelter belts along motorways
	Mediation of visual impacts	Shelter belts around industrial structures
Mediation of flows	Flood protection (cubic metres/ reduced risk of flooding)	Water absorption and attenuation by vegetation
		Control of sediment
		Provision of storage for excess water
	Maintaining baseline flows for water supply (reduced risk of drought)	Supporting service for water provisioning
	Storm protection (reduced risk of damage)	Properties protected by natural sea defences (wetlands, dunes, shelter belts)
	Erosion protection (reduced risk of loss of soil)	Mass stabilisation and control of erosion rates
Biophysical Maintenance	Greenhouse gas sequestration (tonnes)	Excludes carbon storage
	Local climate regulation	Vegetation that enables air circulation
	Pollination	Commonly seen as a supporting or intermediate service

Source: Office for National Statistics

[61] ONS (2017). Principles of Natural Capital Accounting. A background paper for those wanting to understand the concepts and methodology underlying the UK Natural Capital accounts being developed by ONS and Defra. Available at: https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/principlesofnaturalcapitalaccounting

Cultural values

	Description of service	Notes
Physical interactions with nature	Setting for outdoor recreation (No. of visits, or time spent at site)	Walking, hiking, climbing, boating. Note that health is generally viewed as a benefit rather than as a service
	Nature-related tourism (No. of visits, time spent at site)	Bird watching, snorkelling
	Amenity (experiential interactions with nature)	Overlaps with recreation; can include an element of option value.
Intellectual interactions with nature	Educational interactions (No. of visits)	School trips
	Subject matter for scientific research (No. of publications)	Research related to ecosystems
	Heritage preservation (cultural archive)	
	Ex situ entertainment viewing	Documentaries on UK ecosystems
	Sense of place / artistic representations	
Spiritual interactions with nature	Symbolic (emblematic plants, animals etc.)	No obvious measures within the UK
	Sacred and religious	
	Existence and bequest	

Source: Office for National Statistics

Appendix 3. Summary guidance for valuing selected services in ecosystem accounting (ONS 2017[62])

PROVISIONING SERVICES	
Woody biomass	Unit resource rent (stumpage prices). Although stumpage prices may include some management overheads and return to capital, these amounts are not expected to be significant.
Wild fish (marine)	Residual resource rent – however this can be low or negative depending on market structure. It may be possible to base estimates on quotas, this would need to be further explored.
Cultivated crops and grass	Residual resource rent. The approach commonly produces quite low values for ecosystem services, but this is not wholly unexpected as anthropogenic inputs into the production are so significant. Different estimates may be possible for different sectors of the industry. Agricultural land valuations, suitably adjusted, may be another option.
Peat	Market prices or residual resource rent.
Water	Residual resource rent for public water supply – but can be low or negative depending on market structure. The residual value method has in our experience to date generated a relatively high resource rent for public water supply which could be considered inconsistent with the concept of a price regulator and normal returns. In future water may be traded between water companies although the prices charged may depend more upon covering the overheads of delivery than on the value of the resource in situ. It is also possible that abstraction licence charges may provide an estimate of the amount of resource rent captured by the Government. Requires further research.
Hydropower and other renewable energy sources	Residual resource rent. Unit resource rent factors used in the national accounts may be transferable to local levels.

REGULATING SERVICES	
Air pollutant absorption	The main challenge is to estimate the physical service provided by the ecosystem. To value the quantity estimated, the relevant Defra health damage costs (depending upon type of pollutant and habitat) offer a simplistic means of valuing a physical service. A more sophisticated method would relate pollution absorbed to population exposure as set out in Defra guidance. Each method assumes that the estimated cost is one that recipients, or society, would be prepared to pay. Damage costs reflect increased mortality, and applied to ecosystem vegetation the benefit is the reduced mortality of pollutant absorption. This is an area of further research.
Noise mitigation	This is an area for further research.
Flood protection	Damage costs avoided from reduced flood risk. This is an area of further research. A particular challenge is that the probability of the service being provided varies across catchments depending on the risk.
Greenhouse gas sequestration	The UK "non-traded" carbon price schedule published by BEIS can be roughly interpreted as (simulated) exchange values in that they are based on the marginal abatement cost (supply) of meeting UK policy targets (demand). The nature of such a market however remains unclear. Existing fledgling ecosystem carbon markets (e.g. based on UK Woodland Carbon Code) are not suitable because they are sensitive to the wider institutional framework around carbon markets. The price of carbon in existing markets should become more representative of the value of carbon sequestration in the future as the institutional setup of markets becomes more established. This should be kept under review.

[62] ONS (2017). Principles of Natural Capital Accounting. A background paper for those wanting to understand the concepts and methodology underlying the UK Natural Capital accounts being developed by ONS and Defra. Available at: https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/principlesofnaturalcapitalaccounting

CULTURAL SERVICES	
Setting for outdoor recreation	Observed travel costs based on MENE can be interpreted as the price of access, together with admission and membership fees. Imputed value required to capture "free" trips.
Nature-related tourism	This is the Resource Rent captured by the tourism sector by taking advantage of the attractions of the natural environment. It could be measurable for an area using ONS micro-data sources. This service would be in addition to the service received by visitors to the natural environment.
Amenity (value of green and blue space)	UK NEA demonstrated substantial natural capital values embedded in property prices, but further work is needed to derive accounting values, based on hedonic pricing methods. May have some overlap with recreational values which will need untangling.
Amenity (value of private gardens)	UK NEA demonstrated substantial ecosystem values embedded in property prices, including domestic gardens, but further work is needed to derive accounting values, based on hedonic pricing methods.
Educational interactions	Some variation of travel cost or opportunity cost approach for educational trips (distinct from recreational). This is an area of further research.
Mental and physical health	This is an area for further testing and research; a key issue is potential overlap with other service values. See discussion of physical services in section 5.

Appendix 4. List of the Natural Capital asset classes and sub-classes used to produce Natural Capital Accounts for Dartmoor and Exmoor National Parks. For Exmoor, LCM 2015 classifications were used. For Dartmoor, LCM classifications were adapted with additional local data on Rhos pasture and dry grassland, adaptations are detailed below.

Exmoor	Dartmoor	Adaptations made to Dartmoor classes
Woodland	Woodland	
Broadleaved	Broadleaved	30% of DNPA Rho pasture extent was subtracted from total LCM broadleaved extent
Coniferous	Coniferous	
Open water	Open water	
Freshwater	Freshwater	
Saltwater	Saltwater	
Mountain/heath/bog	Mountain/heath/bog	
Bog	Bog	
Heather grassland	Heather grassland	
Heather	Heather	
Inland Rock	Inland Rock	
Improved grassland	Improved grassland	Total DNPA dry grassland extent and 25% of Rhos pasture extent was subtracted from total LCM improved grassland extent
Semi-natural grassland	Semi-natural grassland	
Neutral	Species-rich dry	LCM Neutral and Calcareous grassland extents were merged, and DNPA dry grass extent added
Calcareous	Species-rich wet (Rhos pasture)	Based on DNPA Rhos pasture extent (subtracted from LCM extents of acid grassland (45% of Rhos extent), improved grassland (25% of Rhos extent) and broadleaved woodland(30% of Rhos extent))
Acid	Acid	45% of DNPA Rhos pasture extent want subtracted from LCM acid grassland extent
Fen/marsh/swamp	Fen/marsh/swamp	
Arable/horticulture	Arable/horticulture	
Coastal		
Saltmarsh		
Supra-littoral rock		
Supra-littoral sediment		
Littoral rock		
Littoral sediment		

Appendix 5. List of approaches used for quantifying flows of ecosystem goods and services (based on the review of current approaches)

Ecosystem good/service	Quantification	Approach	Comments	Reviewed report(s) using this approach	Alternatives available from reviewed reports?
Recreation (outdoor visit)	Number of environment-related visitors/hectare/year. *Obtained from DNPA/ENPA reports using same approach as reviewed NCA studies.*	STEAM visitor models* were used to obtain visitor number data, and responses from visitor surveys were used to extract proportion of visits related to the Natural Environment.	*For Dartmoor, we used information on visitor numbers obtained from the ORVal model (calibrated for DNPA in a previous project) as these estimates were deemed more reliable. Differences between ORVal and STEAM estimates are outlined in the report. To extract environment-related visit numbers for Dartmoor and Exmoor, 85% of all visits were used, as ENPA visitor survey showed that 85% if all respondents listed "landscape/scenery" as primary reason for visit. Similar data was not available for DNPA. Resulting environmental visitors/hectare/year: Dartmoor: 69, Exmoor: 18	D	Y – MENE (see report for comparison between STEAM and ORVal – which uses MENE data)
Wild food	-	The DEFRA protected areas report used data on numbers of game/deer extracted in each protected area	Whilst in theory possible to replicate this approach to the NPs, data is needed on game and deer numbers extracted within the National Park boundaries each year. Such information was not available.	D	N
Carbon sequestration	Tonnes of CO2/CO2e sequestered/ha/year. Broadleaved woodland: 10.71 Coniferous woodland: 17.51 Open water: -5.4 Bog: NA Heather grassland: 1.61 Heather: 3.45 Improved grassland: NA Acid/calcareous grassland: 1.61 Fen/Marsh/Swamp: 3.91 Species-rich dry grassland: 1.61 Rhos pasture/neutral grassland: 1.55 Arable: -18.65 Saltmarsh: 4.2 Supralittoral sediment: 1.14	Using Carbon sequestration rates based on published studies of sequestration of different habitat types	Estimates used in the RSPB accounts were used for the NPs, as the RSPB study provided comprehensive information across a wide range of habitat types, and sequestration rates were based on a comprehensive literature review. Sequestration rates for bog are unknown, as sequestration is highly dependent on bog condition, for which information was unavailable. Data on improved grassland was unavailable from the reviewed reports. +Data on littoral sediment was unavailable from the RSPB study, estimate from the ONS coastal margin scoping study was used instead.	All	Y

Timber	m³ of overbark harvested/year/ha Broadleaved woodland: 0.5 Coniferous woodland: 7.4	Timber production was estimated by dividing total UK production of softwood and hardwood (Forestry Commission data) by total UK area of coniferous and broadleaved woodland.		D,E	N
Livestock	Numbers of livestock *Obtained for NPs from DEFRA data, not obtained from reviewed reports*	Data on number of livestock was obtained from DEFRA surveys. Livestock yield information was then obtained from other sources to provide estimate of annual production of livestock.	Whilst livestock numbers could be obtained from DEFRA surveys for Dartmoor and Exmoor, information on livestock yield could not be located. Therefore, only "total livestock numbers" within the National Park could be estimated. This does not take into account that some animals take multiple years to mature, and some animals are used only as breeding stock and not used for marketing. The estimates provided for Dartmoor and Exmoor therefore represent the total livestock in the park, not an annual value flow, and estimates are therefore inflated (see report for further detail).	D	N
Crops	Tonnes of yield/ha/year for various crop types oats: 6 oilseed rape: 3.7 spring barley: 5.5 winter barley: 7.1 wheat: 8.1 linseed: 1.5 sugar beet: 60.7 Peas & beans: 2.4 Potatoes (early): 15 Potatoes (main crop): 33	Obtained from DEFRA agricultural datasets ("Agriculture in the United Kingdom", "Cereal production survey" and "oilseed rape survey"	For some of these crops, regional yield data was available (oats, oilseed rape, spring barley, winter barley, wheat). When this was the case, figures for the southwest were used.	D,N	N
Drinking water	-	In the DEFRA study for protected areas, data was used on annual m³ of freshwater extracted from surface and ground within the area of interest.	Estimates of water extraction volumes in the National Parks could not be extracted within the timeframe of this project. However, the approach outlined here could easily be replicated for the National Parks should extraction data become available.	D	N
Air quality purification	kg of absorbed PM10/ha/year Woodland: 11.91 Bog: NA	The ONS scoping study on air quality shows pollutants capture by broad UK habitat type, dividing by UK habitat	Pollutants other than PM10 could also be considered. Estimates displayed here are obtained by dividing ONS approach used here, DEFRA protected area study also calculated air pollution benefits, but sources underpinning	O	Y

	Heather grassland: 0.64 Heather: 0.42 Improved grassland: 0.24 Semi-natural grassland: 0.46 Arable: 0.27 Coastal margins: 0.67	type extents gives estimates per hectare displayed here.	absorption calculations could not be traced, and this is therefore not available as an alternative approach.		
Minerals	-		Generally not considered by the reviewed NCA studies		
Plants and seeds	-		Generally not considered by the reviewed NCA studies		
Wildlife	-		No current developed methodology for incorporating wildlife into Natural Capital Accounts		
Pollination	Proportion of crop production (and agricultural value) dependent on pollinators Beans: 0.25 Linseed: 0.05	Using worldwide coefficients of pollinator dependence	Oilseed rape and peas have a varied pollinator dependence and could therefore not be quantified. Not all crops of interest for the NP study were included in the pollinator dependency estimates from the Nene Valley study. Oats, Barley, Wheat, Sugar Beet and Potatoes are all not pollinator dependent.	N	N
Flood protection	-	No methodology for quantifying links between assets and levels of flood protection	The Eftec woodland study quantified the amount of woodland positioned in/upstream from flood risk zones. The ONS study on coastal areas provided a value for wetland flood protection, but no data based on which to estimate extent of flood protective wetlands in Exmoor.		
Volunteering	Number of volunteer hours per year *Obtained from DNPA/ENPA reports using same approach as reviewed NCA study.*	Data on the number of hours of volunteering work within the area of interest	For Dartmoor and Exmoor, obtained from in-house data	R	N

Notes: **D = Defra NCA for protected areas** (Ref: White, C., Dunscombe, R., Dvarskas, A., Eves, C., Finisdore, J., Kieboom, E., Maclean, I., Obst, C., Rowcroft, P. & Silcock, P. (2015), 'Developing ecosystem accounts for protected areas in England and Scotland', Department for Food, Environment & Rural Affairs/The Scottish Government); **R=accounts for RSPB estate** (Ref: RSPB (2017). Accounting for Nature: A Natural Capital Account of the RSPB's estate in England); **E = Eftec woodland NCA for the UK** (Ref: Cryle, P., Krisht, S., Tinch, R., Provins, A., Dickie, I., Fairhead, A. (2015). Developing UK natural capital accounts: woodland ecosystem accounts. Economics for the Environment Consultancy Ltd (Eftec) in association with Cascade Consulting for the Department for Environment, Food and Rural Affairs (Defra)); **N = Nene Valley report** (Ref: Rouquette, J.R. (2016). Mapping Natural Capital and Ecosystem Services in the Nene Valley. Report for the Nene Valley NIA Project); **O = ONS studies (air quality, valuing flood regulation and valuing coastal areas)** (Ref: Jones, L., Vieno, M., Morton, D., Cryle, P., Holland, M., Carnell, E., Nemitz, E., Hall, J., Beck, R., Reis, S., Pritchard, N., Hayes, F., Mills, G., Koshy, A., Dickie, I. (2017). Developing Estimates for the Valuation of Air Pollution Removal in Ecosystem Accounts. Final report for Office of National Statistics, July 2017; Richard Smithers, Outi Korkeala, Guy Whiteley, Shaun Brace, Bex Holmes (2016). Valuing flood-regulation services for inclusion in the UK ecosystem accounts. Ricardo Energy & Environment for the UK Office for National Statistics; Office for National Statistics (ONS) (2016) Scoping the UK coastal margin ecosystem accounts)**.**

Appendix 6. List of the economic valuation assumptions employed (based on the review of current approaches)

Ecosystem good/service	Value (2015£)	Valuation Approach	Comment	Reviewed report(s) using this approach	Alternatives available?
Recreation (outdoor visit)	Woodlands: £3.61/visit River, lake or canal: £1.96/visit Mountains, moors, heathlands: £5.43/visit Semi-natural grassland: £1.67/visit Enclosed farmland: £1.67/visit Coastal: £4.28/visit	Meta-analysis of valuation studies	The values per visit were taken from the Sen et al. (2014) study. This is a meta-analysis based on about 300 estimates of the value of recreational visits to different habitats. Reviewed studies drew on a mix of stated and revealed preference studies providing WTP information. This is a standard approach employed by the reviewed reports.	all	NO
Wild food	-	Resource rent, assumed to be equal to wholesale market prices	Wild food, game and fish were not included in the natural capital accounts developed for Dartmoor and Exmoor because of insufficient availability on the quantification of this ecosystem good/service.	D	NO
Carbon sequestration	£62.39/tonne of CO_{2e} sequestered	Abatement cost approach	The value of carbon sequestration is based on DECC non-traded carbon prices (central estimate) for 2015. This is a pretty standard approach employed by the reviewed reports	all	NO
Timber	£14.74/m^3 standing hardwood £ 14.07/m^3 overbark softwood	Literature review Resource rent, approximated by using FC sales prices of harvested timber	For softwood timber production, standing price per cubic meter of overbark (or stumpage price) is used (Forestry Commission data). In the absence of equivalent prices for hardwood, information was extracted from a review of the literature	D E	YES
Livestock	Dairy cows: £1021.44/cow Finishing cattle: £157.36/head Calves (<1 year): £94.23/head Breeding pig: £24.23/pig Breeding ewe: £31.10/ewe Lamb (<1 year): £2.83/ewe Poultry: £0.45/head	Resource rent approach (farm gross margins based on John Nix Pocketbook for Farm management 2018)	The Defra report considered market prices for livestock and then applied some resource rent ratios to estimate the resource rents for livestock. We opted for considering a more readily applicable but equivalent approach based on the farm gross margins (which, similarly to resource rents are also calculated starting from market prices, after subtracting variable costs).	D	YES
Crops	Wheat (milling, winter): £80.09/tonne Wheat (feed, winter): £81.98/tonne Barley (malting, winter): £81.98/tonne Barley (feed, winter): £71.61/tonne Spring barley: £94.61/tonne Oats (winter): £78.21/tonne	Resource rent approach (farm gross margins based on John Nix Pocketbook for Farm management 2018)	The Defra report considered market prices for livestock and then applied some resource rent ratios to estimate the resource rents for livestock. We opted for considering a more readily applicable but equivalent approach based on the farm gross	D	YES

	Oil seed rape (average price, winter): £178.09/tonne Linseed (spring): £219.55/tonne Sugar beet (average price): £9.42/tonne Field peas (marrowfats): £111.19/tonne Field beans (winter): £102.71/tonne Field beans (spring): £103.65/tonne Potatoes (early potatoes): £97.06/tonne Potatoes (maincrop potatoes, based on all potatoes): £63.13/tonne		margins (which, similarly to resource rents are also calculated starting from market prices, after subtracting variable costs).		
Drinking water	0.15/m³ of abstracted water	Resource rent approach	The value provided for the abstraction of drinking water for public use are calculated by subtracting human input from the market price of water (set by Ofwat).	D	YES
Air quality purification	£16.23/kg of PM_{10} absorbed	Damage cost avoided	Information on the value of air quality improvement is estimated by considering the health benefits (in terms of damage avoided) resulting from lower concentrations of PM_{10} in the air. The figure of £15,041/tonne of PM_{10} absorbed (2010 prices) was derived from the Interdepartmental Group on Costs and Benefits (IGCB) report and specifically refers to rural areas	D	YES
Minerals	-	-	Generally not considered by the reviewed NCA studies	none	NO
Plants and seeds	-	-	Generally not considered by the reviewed NCA studies	none	NO
Wildlife	-	-	No information available on the monetary value of wildlife preservation	none	NO
Volunteering	£7.31/hour of volunteering (lower bound)	Costs avoided	Heritage Lottery Fund value of work per hour for unskilled workers	R	NO
Pollination	oilseed rape: mixed response field beans: 0.25 linseed: 0.05 apples (dessert apples): 0.45 apples (culinary apples): 0.28 pears: 0.09 plums: 0.08 cherries: 0.04 oats: 0 barley: 0 wheat: 0 sugar beet: 0 peas: mixed response	Pollinator dependency	Pollinator-dependency coefficients are applied to the farm gross margins calculated for agriculture (crop) to determine the value of crop production attributable to the existence of pollinators (the value that, in the absence of pollinators, would be lost).	N	NO

	potatoes: 0				
Flood protection	Reducing flood risks in woodlands: Lower bound: £22.48/ha Upper bound: £27.18/ha	Replacement cost approach	Estimates of avoided expenditures on flood-related defenses due to reduced flood risks	O	NO
	For coastal areas: Lower bound: £1679.18/meter Upper bound: £1740.95/meter		Average costs avoided – savings (per km) in terms of not needing to replace coastal margin habitats with man-made sea walls due to lower flood risks	D	NO
	For saltmarshes: £1.775/metre of saltmarsh (year unknown)	Avoided costs	Cost savings in seawall investments that should be otherwise incurred in the absence of flood protection services provided by saltmarshes	O	NO

Notes: **D = Defra NCA for protected areas** (Ref: White, C., Dunscombe, R., Dvarskas, A., Eves, C., Finisdore, J., Kieboom, E., Maclean, I., Obst, C., Rowcroft, P. & Silcock, P. (2015), 'Developing ecosystem accounts for protected areas in England and Scotland', Department for Food, Environment & Rural Affairs/The Scottish Government); **R=accounts for RSPB estate** (Ref: RSPB (2017). Accounting for Nature: A Natural Capital Account of the RSPB's estate in England); **E = Eftec woodland NCA for the UK** (Ref: Cryle, P., Krisht, S., Tinch, R., Provins, A., Dickie, I., Fairhead, A. (2015). Developing UK natural capital accounts: woodland ecosystem accounts. Economics for the Environment Consultancy Ltd (Eftec) in association with Cascade Consulting for the Department for Environment, Food and Rural Affairs (Defra)); **N = Nene Valley report** (Ref: Rouquette, J.R. (2016). Mapping Natural Capital and Ecosystem Services in the Nene Valley. Report for the Nene Valley NIA Project); **O = ONS studies (valuing flood regulation and valuing coastal areas)** (Ref: Richard Smithers, Outi Korkeala, Guy Whiteley, Shaun Brace, Bex Holmes (2016). Valuing flood-regulation services for inclusion in the UK ecosystem accounts. Ricardo Energy & Environment for the UK Office for National Statistics; Office for National Statistics (ONS) (2016) Scoping the UK coastal margin ecosystem accounts)**.**

Appendix 7. Natural Capital Account table for Exmoor National Park. Stock extents are based on Land Cover Map 2015.

STOCKS		GOODS & SERVICES																TOTAL
		Recreation		Climate regulation		Timber		Livestock		Crops		Volunteering		Air quality		Pollination		
Natural capital stock	Stock extent (ha)	Annual visitors	Value	Annual tonnes of CO2e seques.	Value	Annual m3 overbark	Value	Total livestock no.	Value	Annual tonnes	Value	Annual hours	Value	Annual kg PM10 absorbed	Value	Annual pollinator-depedent tonnes	Value	
Total goods & services	69890	1258024	£2,762,899	130731	£8,156,890	28935	£426,677	362840	£7,257,879	21589	£1,613,595	27288	£199,436	155495	£2,472,710.48	71	£7,432	£22,897,519
Woodland	11254	202572	£730,693	143501	£8,953,676	28935	£426,677			0	£0			134035	£2,174,901.42	0	£0	£12,285,948
Broadleaved	7876	141768	£511,368	84352	£5,263,109	3938	£60,443			0	£0			93803	£1,522,083.13	0	£0	
Coniferous	3378	60804	£219,325	59149	£3,690,566	24997	£366,234			0	£0			40232	£652,818.29	0	£0	
Open water	234	4212	£8,264	-999	-£62,332	0	£0			0	£0			0	£0.00	0	£0	-£54,069
Freshwater	185	3330	£6,533	-999	-£62,332	0	£0			0	£0			0	£0.00	0	£0	
Saltwater	49	882	£1,730			0	£0			0	£0			0	£0.00	0	£0	
Mountain/heath/bog	3407	61324	£333,368	10992	£685,852	0	£0			0	£0			1496	£23,238.73	0	£0	£1,042,459
Bog	26	468	£2,544			0	£0			0	£0					0	£0	
Heather grassalnd	356	6408	£34,835	573	£35,762	0	£0			0	£0			228	£2,657.23	0	£0	
Heather	3020	54360	£295,510	10419	£650,090	0	£0			0	£0			1268	£20,581.51	0	£0	
Inland Rock	5	88	£479	0	£0	0	£0			0	£0			0	£0.00	0	£0	
Improved grassland	34113	614034	£1,022,730			0	£0			0	£0			8187	£132,847.09	0	£0	£1,155,577
Semi-natural grassland	17259	310662	£517,436	27766	£1,732,422	0	£0			0	£0			10982	£128,823.28	0	£0	£2,378,682
Neutral	357	6426	£10,703	553	£34,526	0	£0			0	£0			164	£2,664.69	0	£0	
Calcareous	0	0	£0	0	£0	0	£0			0	£0			0	£0.00	0	£0	
Acid	16902	304236	£506,733	27212	£1,697,896	0	£0			0	£0			10817	£126,158.59	0	£0	
Fen/marsh/swamp	0	0	£0	0	£0	0	£0			0	£0			0	£0.00	0	£0	
Arable/horticulture	2736	49248	£82,027	-51026	-£3,183,773	0	£0			21589	£1,613,595			739	£11,986.73	71	£7,432	-£1,468,733
oats	70									420	£32,817					0	£0	
oilseed rape	436									1613	£287,312							
spring barley	266									1464	£137,949					0	£0	
winter barley	268									1905	£156,176					0	£0	
wheat	1208									9786	£783,807					0	£0	
linseed	11									16	£3,525					1	£176	
sugar beet	64									3898	£36,735					0	£0	
peas	30									72	£7,998							
field beans	118									283	£29,025					71	£7,256	
potatoes (early)	7									107	£10,389					0	£0	
potatoes (main crops)	61									2025	£127,860					0	£0	
other	196																	
Coastal	887	15971	£68,381	498	£31,046	0	£0	0	£0	0	£0			56	£913.22	0	£0	£100,340
Saltmarsh	84	1512	£6,474	353	£22,013	0	£0	0	£0	0	£0			56	£913.22	0	£0	
Suppra-littoral rock	471	8478	£36,298	0	£0	0	£0	0	£0	0	£0			0	£0.00	0	£0	
Suppra-littoral sediment	3	59	£254	4	£235	0	£0	0	£0	0	£0			0	£0.00	0	£0	
Littoral rock	90	1620	£6,936	0	£0	0	£0	0	£0	0	£0			0	£0.00	0	£0	
Littoral sediment	239	4302	£18,419	141	£8,798	0	£0	0	£0	0	£0.00			0	£0.00	0	£0.00	

Appendix 8. Natural Capital Account table for Dartmoor National Park. Stock extents are adapted from Land Cover Map 2015 (see Appendix 4)

STOCKS		GOODS & SERVICES														TOTAL
		Recreation		Climate regulation		Timber		Livestock		Crops		Air quality		Pollination		
Natural capital stock	Stock extent (ha)	Annual visitors	Value	Annual tonnes of CO2e seques.	Value	Annual m3 overbark	Value	Total livestock no.	Value	Annual tonnes	Value	Annual kg PM10 absorbed	Value	Annual pollinator-dependent tonnes	Value	
All stocks	**94322**	**6508218**	**£15,516,528**	**185675**	**£11,585,099**	**32000**	**£455,630**	**282088**	**£8,193,537**	**17218**	**£1,286,865**	**171888**	**£2,788,461**	**57**	**£5,928**	**£39,832,048.46**
Woodland	**12194**	**841386**	**£3,034,945**	**156125**	**£9,741,358**	**32000**	**£455,630**			**0**	**£0**	**145231**	**£2,356,562**	**0**	**£0**	**£15,588,495.40**
Broadleaved	8440	582360	£2,100,618	90392	£5,640,000	4220	£64,771			0	£0	100520	£1,631,079	**0**	**£0**	
Coniferous	3754	259026	£934,327	65733	£4,101,358	27780	£390,859			0	£0	44710	£725,482	**0**	**£0**	
Open water	**217**	**14973**	**£29,376**	**-1172**	**-£73,114**	**0**	**£0**			**0**	**£0**	**0**	**£0**	**0**	**£0**	**-£43,738.15**
Freshwater	217	14973	£29,376	-1172	-£73,114	0	0			0	£0	0	£0	**0**	**£0**	
Saltwater	0	0	£0	0	£0	0	0			0	£0	0	£0	**0**	**£0**	
Mountain/heath/bog	**11679**	**805851**	**£4,380,738**	**8654**	**£539,991**	**0**	**0**			**0**	**£0**	**1153**	**£18,055**	**0**	**£0**	**£4,938,783.57**
Bog	8928	616032	£3,348,851			0	0			0	£0			**0**	**£0**	
Heather grassland	224	15456	£84,021	361	£22,502	0	0			0	£0	143	£1,672	**0**	**£0**	
Heather	2404	165876	£901,729	8294	£517,489	0	0			0	£0	1010	£16,383	**0**	**£0**	
Inland Rock	123	8487	£46,137	0	£0	0	0			0	£0	0	£0	**0**	**£0**	
Improved grassland	**29035**	**2003415**	**£3,336,871**			**0**	**0**			**0**	**£0**	**6968**	**£113,072**	**0**	**£0**	**£3,449,942.46**
Semi-natural grassland	**39015**	**2692035**	**£4,483,830**	**62761**	**£3,915,970**	**0**	**0**			**0**	**£0**	**17947**	**£291,213**	**0**	**£0**	**£8,691,012.99**
Acid	36595	2525055	£4,205,710	58918	£3,676,164	0	0			0	£0	16834	£273,150	**0**	**£0**	
Fen/marsh/swamp	11	759	£1,264	43	£2,684	0	0			0	£0	5	£82	**0**	**£0**	
Species-rich dry grassland	1107	76383	£127,223	1782	£111,204	0	0			0	£0	509	£8,263	**0**	**£0**	
Rhos pasture	1302	89838	£149,633	2018	£125,919	0	0			0	£0	599	£9,718	**0**	**£0**	
Arable/horticulture	**2182**	**150558**	**£250,768**	**-40694**	**-£2,539,106**	**0**	**0**			**17218**	**£1,286,865**	**589**	**£9,560**	**57**	**£5,928**	**-£985,985.23**
oats	56					0	0			335	£26,172			0	£0	
oilseed rape	348					0	0			1287	£229,135					
spring barley	212					0	0			1168	£110,017			0	£0	
winter barley	214					0	0			1519	£124,553			0	£0	
wheat	964					0	0			7804	£625,098			0	£0	
linseed	9					0	0			13	£2,811			1	£141	
sugar beet	51					0	0			3109	£29,297			0	£0	
peas	24					0	0			57	£6,379					
field beans	94					0	0			225	£23,148			56	£5,787	
potatoes early	6					0	0			85	£8,285			0	£0	
potatoes main crop	49					0	0			1615	£101,970			0	£0	
remainder (other)	157					0	0									

Local Natural Capital Accounting: does it deliver useful management information?

A case study of Dartmoor and Exmoor National Parks

sweep
Briefing Note

This briefing note sets out a series of recommendations to address some of the key barriers hindering the practical application of Natural Capital Accounting at a subnational scale. It draws on the conclusions from a Natural Capital Accounting project developed with two UK National Parks (Dartmoor and Exmoor National Parks) and is Local Natural Capital Accounting: does it deliver useful management information? A case study of Dartmoor and Exmoor National Parks, June 2020. This work was undertaken as part of the NERC-funded SWEEP programme (South West Partnership for Environmental and Economic Prosperity)[1].

Who should read this?

- National, regional and local government policy makers – to inform better guidance, policy and support around delivering Natural Capital approaches and Natural Capital Accounts .
- Other National Parks, public bodies such as Natural England and the Environment Agency, charities, trusts and any other organisation experience before undertaking their own Natural Capital Accounting process.

What is this about, and why is it important?

The UK's National Parks have been encouraged to develop Natural Capital Accounts as part of the Glover's Landscapes review: National Parks and AONBs and by the government's own Natural Capital Committee. This is in support of the UK government's 25 Year Environment Plan ambition that 'the UK intends to use a natural capital approach' to enable local decision makers to be 'equipped with the tools they need to

Despite the existence of international guidance (the System of Environmental-Economic Accounting, SEEA) and national recommendations (the ONS/ Defra Principles of Natural Capital Accounting),

Natural Capital Accounts at a subnational scale; something acknowledged in the Enabling a Natural Capital Approach (ENCA): Guidance report and in the 2019 Sixth Natural Capital Committee report.

In this context, a question of key concern is whether large-scale approaches are appropriate at a smaller scale, where issues such as local variation in the delivery of ecosystem services and gaps in data require multiple assumptions to build accounts.

In response, the SWEEP project critically assessed the challenges in the development of Natural Capital Accounts at subnational scale, outlining the merits and limitations of existing approaches and drawing lessons learnt to inform ongoing discussions. To explore these issues, the project developed a set of Natural Capital Accounts for Dartmoor National Park Authority and Exmoor National Park Authority in the South West of England.

"This was a really useful piece of work bringing

the National Parks. We entered into this process to develop a robust natural capital account for the National Park, we hope the learning from this Project can be shared to improve the tools available and ensure a consistent approach."

Ally Kohler, Director of Conservation and Communities, Dartmoor National Park

"The SWEEP project delivered a rigorous and robust assessment of natural capital accounting in the National Park. With an expectation that the natural capital approach will form the basis of our future planning and decision-making, I feel it's very important we feedback the learning to Government in order to improve the processes and tools."

Clare Reid, Head of Strategy and Performance, Exmoor National Park

NERC SCIENCE OF THE ENVIRONMENT

DARTMOOR NATIONAL PARK

EXMOOR NATIONAL PARK

Recommendations for action

Accounting as a management tool, both generally, but

1. **Building greater understanding of Natural Capital Accounting** - especially among environmental organisations, about what a Natural Capital Account is (a snapshot of the situation in time) and what it is not (a general project appraisal tool). Making this distinction (as highlighted in the ENCA guidance) is important to ensure that the right tool is used to answer the right question.

2. **Developing specific step-by-step, tailored Natural Capital Accounting guidance** - as urged by the Natural Capital Committee in their 2019 report, to ensure that consistent, robust and comparable approaches are used in the development of Natural Capital Accounts at subnational scales.

3. **Creating new Natural Capital Accounting tools** - public money needs to be invested in the design and development of publicly available tools, tailored for non-specialists, to support the development of Natural Capital Accounts where interdisciplinary knowledge, technical and analytical skills are not available in-house.

4. **More routine collection of locally-specific, easily accessible, data** - to ensure greater

   condition, ecosystem services' A good example for achieving this are the SWEEP habitat mapping tools.

5. **Greater access to knowledge on the ecological condition of natural assets, upon which the provision of ecosystem services depends** - to enable a better understanding of the

6. **Greater consideration of the rate of extraction and/or use (and state) of natural assets over time**

   given point and inform sustainable management decisions.

7. **Improving the quantification and valuation of some ecosystem services** - through further

   to ensure that public goods, such as biodiversity

   landscape values, can be suitably represented in Natural Capital Accounts. Despite tools such as NEVO, very little such information is publicly available through datasets, which represents a major data gap.

8. **Greater inclusion of spatial aspects of natural assets in Natural Capital Accounting guidance**

   ecosystem goods and services and its value to people. This will improve the accuracy and usefulness of the Natural Capital Accounting method and help to inform spatial planning decisions.

9. **More accurate representation of costs for the maintenance and management of natural capital stocks** - in Natural Capital

   a consistent basis. This aligns with recommendations in the ENCA report.

10. **Clearer communication of uncertainties** - such as data gaps and limitations in available methodologies, when reporting Natural Capital Accounting results, to ensure an accurate interpretation and increased transparency. This could be achieved, for example, through the

    .

For further information please contact either Dr. Michela Faccioli (M.Faccioli@exeter.ac.uk) or the SWEEP team (sweep@exeter.ac.uk).

[1] SWEEP team: Dr Michela Faccioli, Dr Sara Zonneveld, Prof. Charles Tyler and Prof. Brett Day, from the University of Exeter.

Published May 2021

Local Natural Capital Accounting: does it deliver useful management information?

A case study of Dartmoor and Exmoor National Parks

EXTENDED SUMMARY

November 2019

Report to Exmoor National Park Authority and Dartmoor National Park Authority

Michela Faccioli
Sara Zonneveld
Charles Tyler
Brett Day

This is an extended summary of the report titled "Local Natural Capital Accounting: does it deliver useful management information? A case study of Dartmoor and Exmoor National Parks".

Acknowledgements:

The research in this report was funded by the Natural Environment Research Council (NERC) through the SWEEP project [grant number NE/P011217/1].

Introduction

The 25 Year Environment Plan represents an important step towards placing the protection of Natural Capital at the top of the political agenda. Natural Capital (or natural assets) - the habitats and ecosystems that underpin our natural environment - provide a wide variety of ecosystem goods and services (e.g. clean air and water, food and timber, recreation opportunities) that people appreciate. In most cases, though, the benefits provided by nature are 'invisible' and are not adequately accounted for in decision-making processes, which leads, for example, to environmental degradation. Many environmental goods and services are 'invisible' mostly because they don't have a given price. This way, natural resources are assumed to be exploitable at no or little cost, where in fact depleting the environment has a wider social cost and preserving nature generates social welfare benefits that have an economic value.

Natural Capital Accounting can be used as a tool to make the costs of environmental degradation and the benefits of environmental protection visible. Natural Capital Accounts record changes in the extent and condition of natural assets over time, measure the resulting variation in the flow of ecosystem goods and services provided and, through economic valuation techniques, allow the quantification of the costs and benefits of such changes in service flows. These costs and benefits are frequently measured in monetary terms to consider a common metric that policy-makers can use to compare the costs and benefits of environmental degradation and conservation with other types of costs and benefits.

Within the field of natural capital accounting, most efforts to date have focused on the development of *national* accounts. Only recently, the Natural Capital Committee has emphasised the need for more efforts into developing natural capital accounting *at organisational* scale – at the level of businesses, NGOs or governmental departments, i.e. those who own and/or manage land on a more local or regional scale. The role of such businesses and organisations is crucial for the successful preservation of the natural environment and the delivery of ecosystem goods and services. This is particularly true in the case of environmentally-facing organisations, such as National Park Authorities.

Natural Capital accounting at organisational level can fulfil many purposes. For example, it can "*document an organisation's ownership, liability and assets related to natural capital*" (EFTEC 2015)[1] and it can help in balancing competing priorities and identifying opportunities to enhance ecosystem functioning. It can also help in promoting awareness about the importance of Natural Capital and the interdependencies between the environment and people. It can be useful to identify trade-offs between different land uses and/or ecosystem services and be employed to provide evidence about the importance and value of given natural assets or ecosystem services to influence legislative and funding decisions.

[1] Eftec (2015). Developing Corporate Natural Capital Accounts. Final Report for the Natural Capital Committee. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/516968/ncc-research-cnca-final-report.pdf

Whilst being increasingly encouraged to produce Natural Capital Accounts, many organisations often struggle with the task. They frequently lack the data, expertise and/or resources to comprehensively monitor all their Natural Capital, identify the ecosystem goods and services, and quantify the wider benefits in economic terms, which can make the development of Natural Capital Accounts challenging.

Several organisations have attempted the development of Natural Capital Accounts at a local and/or regional scale. In the absence of any clear methodological guidance and in-house expertise, those efforts have sought to adapt methods of Natural Capital accounting developed for application in international and national accounting exercises. One concerns is that such methods may not necessarily be appropriate or suitable for accounting at the local or organisational scale.

In this report we critically assess the advantages and disadvantages (potential limitations) of the currently used methodologies in natural capital accounting at a local, organisational scale. To this aim, we review recent efforts, scoping and pilot case studies of Natural Capital Accounts developed with or for UK organisations which are heavily involved in the conservation or management of the environment. We replicate their approaches to produce Natural Capital accounts for two National Park Authorities. We also test the sensitivity of the accounts to the use of different data sources and methodologies, and explore potential ways in which organisations can incorporate additional data and expertise to improve the overall accuracy and usefulness of the accounts. For this project, which is part of the NERC-funded programme SWEEP (South West Partnership for Environmental and Economic Prosperity), we focused on Dartmoor and Exmoor National Parks as our case study areas.

Natural Capital Accounting explained

Natural Capital accounting represents a much-needed addition to the System of National Accounts (SNA), as it provides a more complete picture of the economic wealth of a nation by including the value generated by the environment to people.

The framework underlying Natural Capital Accounting is based on the Natural Capital approach (Figure 1) - a way of thinking about nature as a production system that provides humans with flows of valuable goods and services.

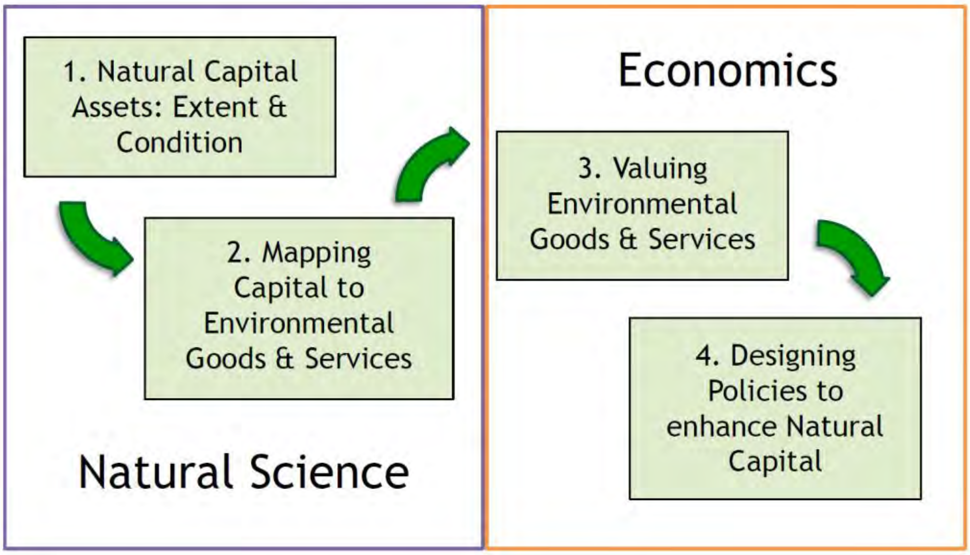


Figure 1. The steps of the Natural Capital approach

The first step in the Natural Capital approach involves establishing the extent and condition of Natural Capital assets or stocks. The second step focuses on mapping the pathways through which Natural Capital provides flows of ecosystem goods and services. The next step in the approach is to apply methods developed by economists to establish the economic value of those flows (step 3). The last step in the Natural Capital approach consists of using the information from step 1 to 3 to inform decision-making, e.g. to design policies and management practices to enhance Natural Capital and maximise the delivery of Ecosystem Goods and Services.

Natural Capital Accounting uses the steps outlined above to produce a structured account to record information about the stocks, Ecosystem Goods and Services, and their monetary value for a given area of interest (such as the area of land managed by an environmental organisation). Currently, practitioners producing Natural Capital Accounts typically rely on the use of readily available datasets to measure natural assets (e.g. land cover maps) and ecosystem services (e.g. ecological literature on Carbon storage by habitat type). Once goods and services are quantified, this information is generally multiplied by per unit values (based on a range of valuation figures and approaches available from the literature) to compute the total economic value. More information on the principles underlying Natural Capital Accounting and the economic techniques used to value Ecosystem Goods and Services, can be found in the full report.

Methodology

The methodology followed to produce Natural Capital accounts for Dartmoor and Exmoor national Parks is based on a review of a selection of publicly available Natural Capital accounting scoping studies/reports and of ecological and environmental economics literature, supplemented with information collected from consultations with management and technical staff from both National Parks.

After identifying Dartmoor and Exmoor National Park Authorities' aspirations regarding the use of Natural Capital Accounts to inform their decision-making, we reviewed the methodologies adopted by the selected (scoping) studies and replicated them to build Natural Capital Accounts for the year 2015 for the full National Park area. The following reports were used to review current practices in natural capital accounting at local and/or organisational scale:

- White, C., Dunscombe, R., Dvarskas, A., Eves, C., Finisdore, J., Kieboom, E., Maclean, I., Obst, C., Rowcroft, P. & Silcock, P. (2015), '**Developing ecosystem accounts for protected areas in England and Scotland'**, Department for Food, Environment & Rural Affairs/The Scottish Government
- RSPB (2017). **Accounting for Nature: A Natural Capital Account of the RSPB's estate in England**
- Rouquette, J.R. (2016). **Mapping Natural Capital and Ecosystem Services in the Nene Valley.** Report for the Nene Valley NIA Project.
- Cryle, P., Krisht, S., Tinch, R., Provins, A., Dickie, I., Fairhead, A. (2015**). Developing UK natural capital accounts: woodland ecosystem accounts.** Economics for the Environment Consultancy Ltd (Eftec) in association with Cascade Consulting for the Department for Environment, Food and Rural Affairs (Defra)
- Office for National Statistics scoping studies:
    - Jones, L., Vieno, M., Morton, D., Cryle, P., Holland, M., Carnell, E., Nemitz, E., Hall, J., Beck, R., Reis, S., Pritchard, N., Hayes, F., Mills, G., Koshy, A., Dickie, I. (2017). **Developing Estimates for the Valuation of Air Pollution Removal in Ecosystem Accounts.** Final report for Office of National Statistics, July 2017
    - Richard Smithers, Outi Korkeala, Guy Whiteley, Shaun Brace, Bex Holmes (2016). **Valuing flood-regulation services for inclusion in the UK ecosystem accounts.** Ricardo Energy & Environment for the UK Office for National Statistics
    - Office for National Statistics (ONS) (2016) **Scoping the UK coastal margin ecosystem accounts**

We closely replicated the reviewed approaches to Natural Capital accounting (or the closest approximation possible) when measuring the extent of the various Natural Capital assets (using Land Cover Map data, adapted for DNPA – see full report for details), the amount of Ecosystem Good and Service flows and their value. We next tested and discussed the sensitivity of the account results to different assumptions available from the reviewed studies regarding quantifications of the natural assets, flows of ecosystem services and goods and values. In this process, we also highlighted limitations of the reviewed and replicated methodologies, and suggest potential ways to improve the accounts. We concluded by critically discussing the usefulness of Natural Capital Accounts to meet management aspirations and inform decisions, by referring to the consultations held with and feedback received from National Park Authority staff at the various stages of the project.

Results and discussion

NATURAL CAPITAL ACCOUNTS FOR DARTMOOR AND EXMOOR

Through replicating the methodologies that practitioners have employed in the reviewed Natural Capital Accounts, we drafted a Natural Capital flow account for the year 2015 for Dartmoor and Exmoor National Parks. In Table 2 and 3, benefits are reported by ecosystem good and service (each column) and, where possible and applicable, also by the different Natural Capital asset classes (each row) (e.g. "woodland") - please refer to the full report for a breakdown by habitat sub-classes (e.g. coniferous vs. broadleaved woodland). Values are also presented in aggregate form: The total benefits associated with each given ecosystem service across the different natural assets supplying it, are presented in the bottom row. The total values for each Natural Capital stock (right-hand column) are also displayed as the sum of the values associated with all ecosystem services provided by that stock. A colour coded-approach is employed in each table. Green boxes show instances where ecosystem services could be valued successfully (albeit with limitations to the valuation technique in several instances), red boxes reflect those cases where ecosystem services could not be valued successfully. Orange boxes indicate a partial valuation (not all habitat-subtypes could be included), and grey boxes indicate situations where a given ecosystem service is not provided by a given habitat. Blue boxes show the totals for each ecosystem service across all habitat types.

It is important to note that the used methodologies are subject to several limitations, as we will discuss in the rest of this extended summary and in more detail in the full report. These limitations cause part of the estimates provided in tables 2 and 3 to be incomplete or inaccurate. The figures and findings from these tables should therefore not be used without reference to the wider context of this study.

Table 2. Natural Capital account for Exmoor National Park for 2015 (in 2015 GBP).

	PUBLIC BENEFITS			PRIVATE BENEFITS					
	Recreation	Climate regulation	Air quality	Timber	Livestock	Crops	Volunteering	Pollination	**TOTALS**
Woodland	731k	8953k	2175k	427k			X		***12285k***
Open water	8k	-62k					X		-54k
Mountain/heath/bog	333k	685k	23k				X		1042k
Improved grassland	1022k	X	133k				X		1155k
Semi-natural grassland	517k	1732k	129k				X		***2378k***
Arable	82k	-3183k	12k			1613k	X	7k	-1469k
Coastal	68k	31k	1k				X		100k
TOTALS	**2763k**	**8157k**	**2472k**	427k	**7258k**	1613k	199k	7k	**22897k**

Table 3. Natural Capital account for Dartmoor National Park for 2015 (in 2015 GBP).

	PUBLIC BENEFITS			PRIVATE BENEFITS				
	Recreation	Climate regulation	Air quality	Timber	Livestock	Crops	Pollination	**TOTALS**
Woodland	3035k	9741k	2356k	456k				***15588k***
Open water	29k	-73k						-44k
Mountain/heath/bog	4380k	540k	18k					*4939k*
Improved grassland	3337k	X	113k					*3450k*
Semi-natural grassland	4484k	3916k	291k					***8691k***
Arable	251k	-2539k	10k			1287k	6k	-986k
TOTALS	**15516k**	**11585k**	2788k	456k	**8194k**	**1287k**	6k	**39832k**

A number of goods and services of interest (namely game, drinking water, biodiversity, flood protection, plants & seeds and minerals) could not be estimated through replicating the approaches from the reviewed studies (and therefore are missing from Tables 2 and 3). This is either because of insufficient availability of information on the quantity (flow) of Ecosystem Goods and Services produced and/or a lack of monetised estimates of the corresponding benefits.

Based on the results displayed in tables 2 and 3, it is possible to show that Dartmoor and Exmoor National Parks provide a mixture of both public benefits (accruing to multiple individuals representing the entirety or some groups within society) and private benefits (accruing to single individuals or organisations). Whilst volunteering and pollination provide benefits to the public, they are here classed as private benefits due to the fact that they are valued using approaches that capture only the private benefits of these ecosystem services (namely proportion of farm gross margins dependent on pollination and reduced costs for organisations working with volunteers).

In terms of the most valuable ecosystem goods and services provided (based on the results of the Natural Capital Accounts in Tables 2 and 3), similar conclusions can be drawn for both National Parks. In both cases, the most valuable goods and services supplied include two ecosystem goods and services with a public good nature (recreation and carbon sequestration) and one private good (livestock – although see discussion on the limitation of the livestock analysis later in this report).

Both in Dartmoor and Exmoor, woodland habitats provide the highest measured benefits, followed by semi-natural grasslands – in both cases mostly due to the high values associated with carbon sequestration in those habitats. The magnitude of these figures, calculated using a Price x Quantity multiplication, is also driven by the amount of these habitats found within the National Parks (i.e. greater habitat extent contributes to increasing the total value associated with a given ecosystems). Negative values (driven by carbon emissions) are seen for arable land and open water.

LIMITATIONS AND SENSITIVITY TO ALTERNATIVE ESTIMATES

In this section, we discuss some examples of the limitations of the produced Natural Capital Accounts for Exmoor and Dartmoor. We discuss issues around measuring stock extent and quantifying and valuing ecosystem service flows. We test the sensitivity of the results to using alternative estimates, and suggest potential alterations of, and additions to, currently used Natural Capital Accounting approaches to improve account results. For further examples and a wider discussion, see the full report.

Measuring stock extent

A core requirement of any natural capital accounting undertaking is to establish a physical measure of the extents and qualities of the different natural capitals within the region, forming the focus of the account. In nearly all applications, that we reviewed, the practice has been to quantify those assets in unit of areas of habitat and land use. A significant difficulty in those applications is that data on habitat extent and quality is not available or not collected in the consistent and repeated manner required to construct and update an account. Lacking access to locally collected data, a standard alternative has been to use national, often satellite-derived, land cover data, such as the land cover map products generated by CEH.

Level of detail

In our application to Dartmoor and Exmoor National Parks, the CEH national land cover map 2015 data was used to produce the results displayed in Tables 2 and 3. The habitats identifiable from that data are mapped into relatively broad classes, meaning that some habitat variables with local ecological and management relevance (e.g. ancient woodland, Rhos pasture, Bracken) are overlooked. As a result, we sought local datasets, capturing such specific habitat types of interest. Whilst some data were available, these generally did not provide the full spatial coverage or temporal repeatability necessary to produce Natural Capital Accounts.

Classification accuracy

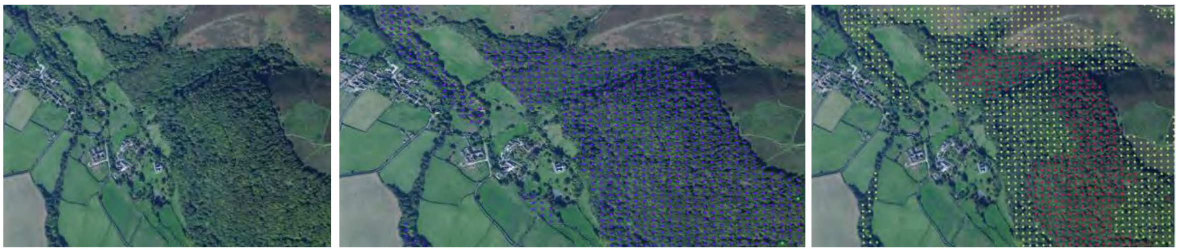
National land cover map data can also be subject to limited classification accuracy when it comes to the identification of Natural Capital stocks at finer spatial resolutions. Based on our produced Natural Capital accounts for Dartmoor and Exmoor, for example, Exmoor's open moors were erroneously classified as acid grassland by the 2015 Land Cover Map data. In order to test whether this misclassification affects account results, we tested what would happen if all acid grassland extent was instead considered to be "heather" (a generalisation used only for testing purposes). Results of this test of re-classification of the stocks, showed that habitat classification inaccuracies can substantially affect the valuation estimates in the Natural Capital Accounts. In fact, the total Natural Capital Account value changes from £22.9 million in the original account to £26.0 million after updating the stock classification assumptions.

Repeatability issues

If the ambition is to produce Natural Capital Accounts over multiple years, to detect variations in natural capital stocks, ecosystem goods/services and value over time, data need to be collected using a repeatable and consistent methodology. Land Cover Map data are available for multiple years (1990, 2000, 2007 and 2015). However, due to changes in the protocol of satellite data imagery classification and modelling, they do not offer consistent methodologies for change detection (see box below).

Case study: increase in broadleaved woodland on Exmoor

LCM data appear to show that broadleaved woodlands on Exmoor have changed in extent from 5,764 ha (2007) to 7,821 ha (2015), suggesting an increase by 2,057 ha in less than 10 years. No evidence could be found of such changes in stocks happening on the ground. A plausible reason for such differences between the two years could therefore be linked to variations in the methodological approach adopted in the Land Cover Map data classification. We therefore visually compare land cover classification based on Land Cover Map data with Google Earth's imageries. Land Cover Map 2007 data seem to better classify broadleaved woodlands (purple dots in image B) compared to Land Cover Map 2015 data (image C). As image C shows, in the LCM 2015 data, habitats other than broadleaved woodlands tend to be classified as broadleaved woodland (yellow dots). This is likely one of the reasons why broadleaved woodland figures in 2015 are so high relative to 2007. In 2015 LCM data, there is also a higher tendency to classify broadleaved or mixed woodlands as coniferous woodland (red dots), which suggests low accuracy in woodland classification routines for this area.



2007 2015

An immediate and significant conclusion is that enabling the development and maintenance of local Natural Capital Accounts requires the development of a targeted programme of repeated habitat extent and quality monitoring. Such data is currently not readily available.

Measuring flows of goods and services

In this section, we discuss examples of factors relating to the methods for the quantification of ecosystem services, which may limit the completeness and/or reliability of Natural Capital Accounts.

Missing data

Missing data is a major limitation when building Natural Capital Accounts following current approaches and methods. For some ecosystem services (i.e. Minerals, Plants and Seeds; Wildlife), no information on the biophysical flows and valuation is readily available from the literature or publicly available datasets. Wildlife is a particular challenge in Natural Capital accounting, an issue which is discussed in more detail in the box below. Game, Drinking Water and Flood Protection are context-specific goods and services and therefore they are not always incorporated into natural capital accounting approaches due to lack of local information. Suitable data on game, deer and fish numbers extracted annually was not available from either of the National Parks. For Flood Risk Regulation no suitable methodology could be identified based on the reviewed reports. Flood risk mitigation is a complex ecosystem service, and the extent of flood risk mitigation depends on the local land use, hydrology, geomorphology and wider ecology, meaning that generalisable methodologies, which can be employed across different case study areas, for quantifying this ecosystem service do not exist. To fill the gaps in the quantification of the flow of these ecosystem goods and services, and thereby improve the account completeness, local data need to be systematically collected to supplement publicly available datasets. For example, no publicly available data on volunteering numbers could be found for Dartmoor. This information gap was however later filled with data held within the National Park Authority (see full report).

Case study. Incorporating wildlife

Incorporating wildlife and biodiversity is a major challenge in the field of Natural Capital Accounting. From an ecological perspective, the first step is to determine which component of wildlife should be captured; it could for example be measured as the abundance or conservation status of a wide range of individual species, or the diversity of selected species or species groups. The next step is then to determine how such information links to ecosystem services enjoyed by humans and, subsequently, how such benefits can be valued (see full report). Even when a suitable measure of biodiversity can be identified, data gaps remain a problem, with ecological survey records often patchy across time and space.

Currently, many organisations simply omit an estimate of wildlife from their accounts, or only quantify certain aspects of the wildlife "stock" (e.g. extent of areas under designation as a proxy for capturing biodiversity), without attempting valuation. One solution could be to monitor changes in abundance and status of key species year-on-year towards the target of "net gain". This information can represent a helpful addition to Natural Capital Accounts to improve the usefulness of the accounts for management decision-making.

Whilst selecting locally relevant wildlife species for monitoring could be preferred for management purposes, such an approach introduces limitations in terms of the comparability across different areas. To ensure that information can be compared between areas of organisations, using biodiversity indicators obtained from national data can be desirable. Publicly available online tools can be used to aid this process. For example, the online tool NEVO developed by the LEEP institute at the University of Exeter uses JNCC species distribution data to estimate species richness for a selected area of interest, using a set list of 100 species from a wide variety of species groups.

Whilst species richness can be a clear indicator for management purposes, other key indicators (such as the status of key species of interest), should also be incorporated into Natural Capital Accounts. This is due to the fact that some key habitats may provide a lower diversity of species, but have great conservation value.

Alternative assumptions

In many cases, a range of alternative biophysical assumptions are available when building Natural Capital Accounts. Different Natural Capital Accounting projects often consider different datasets and underpinning methodologies, which can produce multiple alternative estimates. This is the case, for example, with carbon sequestration and recreation.

Depending on the approach and data considered to measure how many tonnes of carbon are sequestered every year per hectare of broadleaved woodland, carbon sequestration benefit estimates for this habitat type on Exmoor ranged from £2.3 million to £5.3 million.

Multiple methods are also available to estimate visitor numbers. To measure the number of recreationists on Dartmoor, we compared the figures proceeding from two visitor models: STEAM, which has been used in multiple previous accounting studies, and ORVal. STEAM provided an estimate of 21 visits per hectare, resulting in a recreation value of £13.7 million (we will discuss more on the estimates of recreational values later in this extended summary). Using the same valuation methodology, but different figures for the number of visitors per hectare based on the ORVal model, leading to an estimate of 69 visitors per hectare, we obtain a recreational value of £16 million. The two models rely on different methods to estimate the number of visitors to a given area. STEAM only focuses on visits of over four hours, whereas ORVal considers all day visits, including shorter visits as well. It is therefore deemed that

ORVal provides a more accurate picture of the total number of recreationists. However, the estimates derived from STEAM can be used to compare the number of visitors in Dartmoor with those in other National Parks and protected areas which also use STEAM.

More broadly, alternative local and context-specific information on the quantity of given Ecosystem Goods and Services is occasionally available, in addition to national averages. In such circumstances, accounts can be improved by replacing national estimates with local information. We illustrate this point (and the associated implications) in the box below, for the case of crop production.

Case study. Crop proportions and agriculture

Before crop yield and values can be estimated, the total extent of arable land needs to be broken down into different crop types. National figures on agricultural land use can be employed in order to divide the total arable land into crop types, using a proportional allocation based on national averages. However, such an approach is not necessarily accurate for Dartmoor and Exmoor, due to the existence of regional variations in crop distribution. An alternative source of information on crop production is the Farm Business Survey which is used, for instance, in a map-based decision-support tool (NEVO), developed by the university of Exeter. We converted the extent of crop types (as provided in NEVO) into percentages and compared these with those derived based on the reviewed approaches. The results of this comparison are outlined in the table below. The two datasets consider different crops, but when comparing the estimates of production and value for the five crops which were included in both the reviewed studies and NEVO (i.e. wheat, spring barley, winter barley, oilseed rape and sugar beet), substantial differences emerge.

	Dartmoor			
Crop type	**Total production (tonnes) – national crop type proportions**	**Total production (tonnes) – NEVO crop type proportions**	**Value – national crop type proportions**	**Value – NEVO proportions**
Wheat	7804	4719	£1,555,106	£940,310
spring barley	1168	1608	£208,782	£287,580
winter barley	1519	1333	£271,686	£238,310
oilseed rape	1287	1365	£457,778	£485,515
sugar beet	3109	0	£100,393	0

When building natural capital accounts for Dartmoor and Exmoor by following the approaches used in the reviewed studies, the quantification of the amount of livestock present within the National Parks, proved challenging. An additional test that was therefore performed is related to the consideration of alternative approaches for the quantification of livestock production for Natural Capital accounting purposes (see box below).

Case study. Testing for alternative quantifications of livestock

We attempted to replicate the methodology adopted by the reviewed natural capital accounts to quantify the flow of livestock. However, replicating the existing approaches was not possible due to insufficient information provided in the reviewed accounts regarding the adopted methodology for estimating livestock yield. In our exercise, we initially assumed that the annual flow of benefits linked to livestock corresponded to the value (measured in terms of farm gross margins) provided by the sale of the total number of livestock present in a given year on Dartmoor and Exmoor. This is, however, a poor assumption, given that some livestock takes multiple years to mature and other adult animals are kept solely for breeding purposes. We therefore tested for the effect of excluding breeding animals from the livestock count – assuming that these are not slaughtered and sold on the market on the same year and instead kept for future sales once maturity is achieved. Considering approaches used in previous studies, we included the following type of livestock, for which valuation information was also available: dairy herd, beef herd, calves, lambs and fowl. The quantification of the livestock relied on the DEFRA June survey data.

	based on total numbers present		excluding livestock for (likely) breeding purposes	
National Park	**Total animals**	**Value**	**Total animals**	**Value**
Dartmoor National Park	282,088	£8,193,537.42	168,788	£5,093,923.29
Exmoor National Park	362,840	£7,257,878.66	231,523	£3,401,148.79

Excluding the breeding livestock understandably decreased the total number of livestock and led to a lower value of livestock production. This may be an improvement on the original account values, as it is no longer assumed that all animals produce value each year. We believe that excluding breeding livestock is a more credible and conservative approach, compared to the one initially adopted, which assumes that all livestock on Dartmoor or Exmoor are sold or slaughtered on a yearly basis. However, in the absence of data on the exact number of livestock produced and sold on the market for the year of interest, only including non-breeding livestock, may still lead to an over-estimate of annual production. This is because some animals take longer than one year to mature and some lambs and young cattle may be retained for future breeding rather than marketed.

Incomplete ecological information

In previous Natural Capital Accounting studies, a wide range of ecologically complex, but nonetheless crucial, interactions between the natural environment and the provision of ecosystem services are often entirely overlooked. For example, our draft accounts included only one estimate of air quality (PM_{10}), but other indicators of air pollution could be included to improve completeness. In addition, to model flood protection, land use and other geographical factors in the affected area of interest also need to be considered. Another example of complex but nonetheless crucial ecological interactions is between parasitic wasp species and other environmental goods. These species often act as crop pests, but at the same time also support ecosystem service provision through links with a wide range of other organisms.

Overlooking ecosystem condition

When developing a Natural Capital Account, ecosystem condition is often partly or completely overlooked in current approaches. This can be a substantial limitation given that the production of Ecosystem Goods and Services depends on the condition of the underlying natural capital. For example, carbon sequestration in peatlands depends on the ecological condition of peat habitats. Depending on peat condition, peatlands can range from net carbon emission (when in poor condition) to net carbon sequestration (when in good condition). In our case study area, the Climate regulation services provided by bogs/peatlands could not be estimated due to the absence of relevant information (at the scale of interest) regarding the condition of peatlands.

Accounting for aspects related to temporal dynamics

When building Natural Capital Accounts, temporal aspects should be taken into consideration. In most cases, the current methodology just focuses on the amount of goods and services that natural assets provide over the period of one year (flow account). Alternatively, if the desire is to produce an asset account, it is necessary to look into the quantity of goods and services that Natural Capital supplies into the future. The amount of ecosystem service flows and beneficiaries can vary over time, not only due to variations in the stock of Natural Capital, but also because of other factors, such as the change in the number of beneficiaries and users of the good (e.g. due to population growth). Often, an average or outdated figure is used across years, which may misrepresent the actual ecosystem service flows or number of beneficiaries.

A good illustrative example is recreation. The total number of visitors may change over time due to local housing developments and population growth and this can lead to an increase in the total recreation values, even when the habitat extent (natural capital assets) and valuation estimates are kept the same. Not updating the estimates of the number of visitors over the different accounting years considered, would lead to an underestimation of the recreational values. This example illustrates that not only the habitat extents and per-unit values need to be reviewed on an annual basis, but any changes in the quantification of service flows (e.g. numbers of visitors) also need to be updated in the account.

Measuring economic values of goods and services

In the following sub-sections, we discuss a series of factors that have to date been overlooked or insufficiently accounted for in the economic valuation of ecosystem goods and services by the reviewed approaches in Natural Capital accounting.

Missing economic values

Natural Capital accounting practitioners often fail to, or are unable to, include a variety of ecosystem good and services that provide important value flows to people. Based on our exercise, for instance, the benefits provided to society in relation to the existence of plants and animal species, beautiful sceneries and unique/diverse landscapes, as well as the appreciation of cultural heritage are completely missing from Natural Capital accounting case studies to date. This is a particularly significant gap especially if the goal is to develop Natural Capital Accounts for protected natural areas and National Parks, where wildlife, landscape and cultural heritage represent important components of the flows of ecosystem goods and services provided and are significant factors in land-management decision-making. The estimation of the economic values associated with biodiversity, scenery or cultural heritage requires tailored valuation approaches, and methodologies remain largely under-developed. More research is required in the future to develop appropriate techniques to calculate the related economic values.

Partially missing economic value components

In some cases, the values considered in the accounts only provide a partial quantification of the benefits that the environment provides to people. This is the case, for instance, regarding the value of flood risk regulation (when incorporated in the accounts). Such value is often assumed to correspond with costs avoided in terms of flood-related expenditures e.g. on flood protection infrastructures. However, the costs avoided in terms of mental health distress and threats to life in the absence of flooding events is often overlooked, such that the numbers employed in analyses under-estimate the full benefits to people.

Similarly, the benefits of volunteering are often simply equated to the savings for an organisation in terms of labour costs avoided to carry out tasks that are instead done by volunteers. The mental and physical health benefits of spending time outdoors for volunteers is generally not included in the accounts, thereby underestimating the benefits of volunteering.

Accounting for spatial heterogeneity

Spatial aspects have received only limited attention in Natural Capital accounting. Some of the reviewed studies have provided maps of the spatial distribution of the different Natural Capital assets or ecosystem goods and services provided by a given area, but have generally not considered the effect of spatial aspects on the economic values. Whilst, in some cases, the value of the flow of ecosystem services is likely to be insensitive to the spatial configuration of Natural Capital, in many other cases, there may be important spatial elements to account for. For example, people might experience different recreational benefits depending on where recreational opportunities are provided, e.g. closer to or further away from home. The case study in the box below explores the effects of spatial factors on recreational values.

Case study. Testing the role of spatial factors on recreational values

To monetise the value of recreational visits, the reviewed Natural Capital Accounts have commonly relied on a meta-analysis by Sen et al. (2014)[1]. That study specifically controls for information on the visited habitat type, but no other spatial factor is accounted for. We compared this approach to the Outdoor Recreation Valuation (ORVal) Tool, developed by researchers at the University of Exeter. ORVal calculates of the welfare value of a recreational day visits to greenspaces in England and Wales, and incorporates spatial factors by accounting for heterogeneity in the accessibility of different sites, as well as considering the mode of transport and distance travelled by visitors. In addition to accounting for habitat-specific differences in recreational values, the ORVal model also controls for the availability of substitute sites that the individual could have considered for their visit. To illustrate the importance of accounting for spatial factors (beyond habitat-specific differences), we have calculated and compared the recreational values of Dartmoor and Exmoor National Parks using the Sen et al. (2014) and the alternative ORVal-based approaches.

	Sen et al. (2014) estimates	**ORVal estimates**
Dartmoor National Park	£15,200,000	£20,260,274
Exmoor National Park	£2,700,000	£8,023,928

From the comparison, it emerges that the Sen et al. (2014) approach undervalues the recreational values of both Dartmoor and Exmoor National Parks. Differences, though, could be driven by a variety of factors. The first difference across the two studies concerns the estimates of values per habitat. Recreational values per habitat in ORVal are estimated by assuming that the value of a visit to a given habitat site is not constant (as assumed by the Sen et al. (2014) meta-analysis), but can vary depending on the distance of the site from the recreationist and the availability of alternative sites with similar characteristics. This means that some habitats (e.g. mountains, moors and heathlands) tend to be overvalued when using the Sen et al. (2014) estimates, whilst others (e.g. freshwater ecosystems) tend to be undervalued. See the full report for a full comparison between the two approaches in the value per visit per habitat.

A second spatial aspect worth noting is that recreational values are sensitive to accessibility. Recreational values are likely higher in locations with more access points. Assuming homogeneous visitation rates, as done in a range of previously produced Natural Capital Accounts, is not realistic for Dartmoor and Exmoor (and many other recreational sites) and can substantially misrepresent the recreational values of certain portions of the National Park, with important implications in terms of spatial planning and decision-making. To understand how accessibility of sites can affect values and management decision making, we consider a hypothetical example, whereby a new woodland is created north of Princetown in Dartmoor National Park (yellow dot). ORVal then provides information on the welfare value and number of visits not only for the proposed new woodland site (yellow), but also for alternative nearby locations (purple) where the new woodland could be planted instead. As the map illustrates, the recreational benefits associated with such broadleaved woodland creation are greater the closer the site is to accessible areas (with access points and footpaths represented in red). Larger purple dots indicate a larger recreational value.

Accounting for aspects related to temporal dynamics

Natural Capital accounting focuses on recording Natural Capital assets, ecosystem goods/services and the related monetised values, and monitoring how these change over time. Indeed, time is a crucial dimension. The reviewed Natural Capital Accounts tend to present flow accounts, showing the value of the ecosystem goods and services provided for one year of reference, as well as stock accounts, by calculating the net present value of the flow of ecosystem goods and services that the natural assets are expected to provide over a period of time into the future. In order to calculate this, a first assumption that needs to be made concerns the length of time over which an asset is expected to provide goods and services. Another related decision that needs to be taken also concerns how much weight to place on benefits being delivered closer to the present as opposed to in the future (i.e. the discount rate for the calculation of the net present value). A positive discount rate implies that less weight is placed upon flows of benefits that are delivered further in the future (compared to the present). The higher the discount rate, the lower weight is placed on future benefits. The debate around which discount rate is most appropriate is ongoing. Indeed it is possible to argue for a range of different discount rates, and the choice of which to employ in a study can have implications on the total value calculated for given flows of ecosystem goods and services over time and affect long-term environmental decisions.

Testing for the effects of using alternative economic value estimates

For some ecosystem goods and services the reviewed Natural Capital accounting studies have employed different/alternative valuation approaches and figures. The availability of multiple valuation options raises the question of which approach is most appropriate. In most of the reviewed examples of Natural Capital Accounts the methodology employs economic values that originate from national statistics or generic literature reviews. In some cases, such national or generic values can be appropriate. However, in other circumstances this is not the case and local knowledge and expertise can be important in identifying which valuation approach or estimate is most appropriate in the development of a robust Natural Capital Account. For example, some crops (i.e. wheat and barley) may be used for different purposes (i.e. human consumption or animal feed) and different uses can be associated with different economic values.

DISCUSSION OF THE USEFULNESS OF THE ACCOUNTS

At the outset of the project, we discussed the National Park Authorities' aspirations regarding the use of Natural Capital Accounts. A list of aspirations was then compiled. This was revisited at the end of the project to discuss whether the initial expectations about Natural Capital accounting could be met using the approaches which are currently typically used.

The table below reports a list of the main aspirations expressed, at the start of the project, by the National Park Authorities. Each item is colour-coded, with colours giving an indication of the extent to which the produced Natural Capital Accounts were perceived, at the end of the project, to meet the initial aspirations and be useful to inform decision-making. Green indicates that initial aspirations were met; orange that aspirations were only partially met and red that aspirations could not be met.

	Exmoor National Park	Dartmoor National Park	
Green	Provide improved information to feed into the State of the Park report	Provide improved information to feed into the State of the Park report	Green
Red	Provide input into the Environment Land Management Schemes (ELMS)/payment for farming, e.g. by putting value on provided ecosystem services	Explore the use of Natural Capital accounting for investment decision-making, e.g. when needing to prioritise between choice of two management/restoration options	Red
Red	Land ownership/land holdings: understand best use for land owned by Exmoor National Park	Leveraging funding/justifying spending. Understanding the monetary value resulting from e.g. a restoration project, and use this knowledge to leverage money for cost of project	Red
Orange	Use to show where (data) gaps are in decision-making	Influencing management decision-making, e.g. increasing amounts of stocks which are shown to have high value	Red

As shown in the above table, in most cases, the Natural Capital Accounts could not satisfy initial expectations. Both National Park authorities perceived that Natural Capital accounting in its current state, is of only limited usefulness to inform decision-making. It was highlighted that the main usefulness of the accounts is to provide improved information to feed into the State of the Park report. The account has also been useful to illustrate current gaps in the information needed for effective decision-making. However, this ambition could only partially be met due to the lack of completeness of the accounts and the wider limitations outlined in this report.

The other listed ambitions were not delivered for a variety of reasons. For example, the work could not help decision-making about investments, as the account gaps and sensitivity to the underlying data are a constraint to robust information to guide such decisions. The accounts could also not be used to inform the use of National Park Authority-owned land. This is due to a scale issue – an account on the full National Park area cannot provide the detailed info on specific land-holdings. Local, e.g. farm-based accounts would be needed to meet this requirement. Lastly, the remaining aspirations (input into ELMS schemes, justifying spending, prioritising between management options) could not be met due to a mismatch between the perception of what Natural Capital Accounts can be used for and the actual capabilities and applications of Natural Capital Accounts. To inform investment and funding decisions and priorities in management, other tools such as cost-benefit analyses or risk registers should be considered instead of Natural Capital Accounts.

The review of a selection of accounts produced to date revealed that Natural Capital Accounts are often skewed in favour of private (or market-based) goods and only partially include public (or non-market) goods. In the case of organisations such as National Parks, whose remit is to ensure a sustainable use and appropriate conservation of the natural environment, the exclusion of important environmental public goods from the accounts is one of the biggest limitations of Natural Capital Accounting in its present format. This is particularly true in relation to ecosystem goods and services such as biodiversity, wildlife or landscapes, upon which National Parks focus much of their management efforts.

Another topic of interest which the majority of Natural Capital Accounts fail to address, is related to a range of ecosystem services that are very specific to the local area, but of substantial cultural value. These include, for example, the role of bees and heather, contributing to local heather honey production, and Dartmoor and Exmoor ponies, as unique and charismatic species, contributing to the recreational enjoyment of the area (as well as conservation grazing).

It was clear that Natural Capital Accounting can only be as good as the underlying data employed in the process. If, as we have shown, the underlying data are subject to limitations and are inaccurate or incomplete at the spatial scale of interest, Natural Capital accounting will misrepresent the value of the natural environment. For these smaller-scale, organisational Natural Capital Accounts to be informative in the future, more support is needed to supply or collect fit-for-purpose data. In addition, ensuring consistency in the accounting methodology used by different organisations with similar characteristics is essential for comparison purposes.

In conclusion, it became apparent in this study that there are broad perceptions and expectations regarding what a Natural Capital Account can and cannot do. In additions, it was perceived that Natural Capital Accounts, produced using the currently available methodology and datasets, do not deliver the management tool which Dartmoor and Exmoor National Park Authorities may need or hope for. From discussions with both National Park Authorities, a common theme was related to the perceived complexities and challenges associated with Natural Capital Accounting for environmental organisations. Frequent concerns raised were in relation to the limited time, resources and expertise that National Parks would have in-house to design and maintain natural capital accounts, limiting the feasibility and possibly also uptake of this approach. Based on discussions with the National Park Authorities it was felt that perhaps Natural Capital Accounting is not the most useful approach to inform decision-making. When specific management questions arise, cost-benefit analyses of alternative options or risk registers of an organisation's Natural Capital could provide a more helpful piece of information to guide decision-making and investment decisions. However, it needs to be noted these approaches can suffer from similar methodological issues and data shortages as outlined in this report, and these options are therefore likely only appropriate in specific instances, such as smaller case studies, when the management question, staff expertise and data availability allow the use of such approaches.

While it was felt that the underlying idea behind natural capital accounting could prove useful, there has been a consensus that Natural Capital Accounting at a local and/or regional scale is still in its early days, and that the methodology and framework need to be improved substantially before the approach can become useful for informing management decision-making in environmentally-facing organisations such as National Parks. Whilst developing Natural Capital Accounts at organisation level is increasingly encouraged by the Government, there are still considerable gaps in relation to how accounts can be implemented in a way which is useful for decision-making.

LESSONS LEARNT AND RECOMMENDATIONS

1. **More clarity is needed about what a Natural Capital Account is and what it is not.** More clarity is needed on the underlying principles and methods, and there is a need for more awareness regarding the capabilities and potential applications of this approach, particularly in the context of management decision-making. It emerged that Natural Capital Accounts are often mistakenly perceived as project appraisal tools to support decisions regarding alternative investment options. This raises the question of whether alternative decision-support approaches (such as cost-benefit analyses or Natural Capital risk registers) could represent more useful tools to guide management decisions.

2. **Guidelines are needed to support the development of Natural Capital Accounts for local scales and/or environmental organisations**. Clear guidance on the methodology would prevent different organisations using different approaches and it would be beneficial for the development of a consistent and robust approach across organisations, which would be useful for comparability purposes.

3. **Tools for natural capital assessment and monitoring, ecosystem service quantification and valuation are needed to support the development of Natural Capital Accounts and collaborations with experts should be encouraged.** It was felt that the development of Natural Capital Accounts for organisations such as National Park Authorities is challenging due to the limited availability of both resources and expertise to develop and update the accounts. Developing a Natural Capital Account can be highly time-consuming and requires interdisciplinary knowledge and a range of technical and analytical skills, often not available in-house. Publicly available tools, developed by academics or other specialists, but tailored for use by non-specialists, need to be encouraged to help support the development of Natural Capital Accounts. If organisations don't have the necessary resources or skills to develop Natural Capital Account themselves, collaborations with specialists should be encouraged.

4. **Data availability is a major issue and fit-for-purpose data collection for Natural Capital Accounting should be promoted**. There is a lack of data to consistently and reliably measure natural assets over multiple years to detect change. Data on asset condition is also often not available across the entirety of the area of interest. In addition to this, data gaps also exist regarding the quantification of a range of important ecosystem goods and services. There is therefore a need to promote more fit-for-purpose data collection for Natural Capital Accounting purposes, which at its very basic, includes repeatable (multi-year) data on assets across the whole of the National Park, as well as ecosystem service measures for those goods and services which cannot typically be derived from national

data (e.g. water extraction, game harvesting and volunteer numbers).

5. **Valuation methods need to be further progressed to be fit-for-purpose for Natural Capital Accounting**. It emerged that the economic values of private goods provided by areas such as National Parks are relatively well represented, whilst some important public goods supplied are either completely or only partially included in the accounts. Importantly, no established methodology seems to be available to fully value the benefits of important services such as flood protection, cultural heritage and landscape values. More efforts are therefore needed to develop sound valuation methodologies.

6. **Uncertainties need to be made explicit**. Gaps in data and the limitations in the available methodologies need to be explicitly acknowledged when developing Natural Capital Accounting exercises, otherwise there is a risk of account results being open to misinterpretation. Sensitivity tests need to be more systematically performed in accounting exercises and the related estimates of uncertainties need to be reported.

7. **The quantification of the flow of ecosystem goods and services should be better linked to the ecological condition of natural assets.** The capability of natural assets to provide goods and services that benefit people heavily depends on the ecological condition of the stock. Wherever possible, data on asset condition, as well as evidence on the effects of condition on ecosystem service provision, should be included in the accounting process.

8. **The sustainability of extraction and/or use of natural capital stocks needs to be better considered.** Better understanding of the implications of sustainable or unsustainable uses of natural capital stocks is crucial if Natural Capital Accounting is to be used to inform decision-making in the longer term. Flow accounts which only focus on annual ecosystem service supply only provide a partial picture and are not sufficient to inform such decision-making processes. Stock accounts, which not only look at annual flow (e.g. timber extraction), but also the total stock (e.g. total standing timber) could be used to provide an improved decision-making framework.

9. **Spatial aspects need to be better incorporated into Natural Capital Accounting**. Based on the reviewed Natural Capital Accounting studies, we can conclude that only limited consideration has been given to spatial aspects. Given that for the majority of ecosystem goods and services, the location of the natural asset and the associated goods and services is important in driving economic values, spatially explicit natural capital accounting methodologies should be encouraged wherever possible, particularly if decisions about spatial planning are to be made based on the results of the Natural Capital Accounting exercise.

10. **More consideration should be given to the costs of maintaining natural capital stocks for the provision of ecosystem goods and services**. In addition to considering the benefits and values of the ecosystem goods and services provided by natural assets, the costs that

need to be incurred to support the provision of such goods and services, should also be taken into explicit consideration.

<u>Natural Capital Assessment Tool for South West Water:</u>
<u>Ecosystem Service Valuation Framework - Methodology document</u>

Authors: Gemma Delafield, Dr. Michela Faccioli, Prof. Brett Day
Land, Environment, Economics and Policy (LEEP) Institute, University of Exeter Business School

As part of the South West Partnership for Environmental and Economic Prosperity (SWEEP) project, the team at the University of Exeter (Gemma Delafield, Dr. Michela Faccioli and Prof. Brett Day) carried out a simplified natural capital accounting exercise for South West Water. Natural capital accounting is about: 1) identifying changes in natural capital (stock of natural assets) and in the flow of ecosystem services and goods that these natural assets supply; and 2) measure the benefits or costs to society linked to such changes in ecosystem services flows. While it is acknowledged that the environment plays an important role in providing different benefits to people, these benefits are not easily identified. The value of the environment to people is, in most of cases, not reflected in market prices and can therefore be easily omitted from decision-making. To address this shortcoming, economic valuation techniques have been developed over time to quantify, in monetary terms, the increase (or decrease) in wellbeing that people experience following an increase (or decrease) in environmental quality. The aim of this document is to outline the different valuation approaches adopted in the development of the natural capital accounting exercise for South West Water. [1]

In short, the goal of the natural capital accounting exercise designed for South West Water was to summarize the monetized value of the expected environmental and social impacts that are anticipated to result from the interventions planned between 2020 and 2025 in the different business cases participating in the South West Water Upstream Thinking programme. This exercise will be used to guide South West Water business planning and, in particular, to better inform decisions about budget allocation that will be taken as part of the PR19 price review process.

The first steps in the development of the natural capital accounting exercise required the collection of information from the different organizations involved in the Upstream Thinking programme (i.e. Devon Wildlife Trust, Westcountry Rivers Trust, Cornwall Wildlife Trust, Exmoor National Park). Each project manager was asked to provide information about: i) the interventions planned in each of the business cases between 2020 and 2025; and ii) the environmental impacts that are expected to result from the interventions from 2020 to 2045. To collect the relevant information, the team at the University of Exeter designed an Excel spreadsheet tool to be filled in by the different organizations responsible for each of the business cases. In section A of the Excel spreadsheet, partner organizations were requested

[1] For more information on the natural capital accounting framework, we refer the interested reader to: ONS (2017). Principles of Natural Capital Accounting A background paper for those wanting to understand the concepts and methodology underlying the UK Natural Capital accounts being developed by ONS and Defra.
For more details on economic valuation principles and techniques, we refer the interested reader to the following publication: Champ, P.A., Boyle, K.J., Brown, T.C. (2003). A primer on Nonmarket Valuation. Kluwer Academic Publishers, Dordrecht, the Netherlands

to provide information on the planned interventions, including woodland creation/management, grassland management, peatland restoration or other soil management activities, as well as interventions requiring changes in agricultural practices. In section B, project managers were asked to report information about the anticipated downstream impacts on the environment and people that might result from the planned interventions, including improved water quality, increased recreation, as well as reduced flood risk or changes in biodiversity.

Partner organizations were instructed regarding how to fill in the spreadsheet and particular stress was placed upon the importance of providing realistic and justifiable (as quantitative as possible) information regarding future interventions and impacts. If quantitative and accurate assessment could not be provided, the team requested project organizations to supply any qualitative assessment available (based on best guesses). Project managers were also encouraged to report their degree of confidence around the provided estimates to point out any uncertainty. After collecting the information on each business case, some iterations with project managers took place to clarify any unclear point and/or missing data.

Once information was collected from project managers regarding the interventions planned on the environment and the expected impacts, for example, on water quality, biodiversity, flood risks, etc. the team at the University of Exeter attempted to quantify the value (in monetary terms, where possible) of the expected changes in the flow of ecosystem services. To identify how much the different changes in ecosystem goods and services are worth to society, existing valuation evidence was considered. The present document aims to explain the methodology adopted to translate the information gathered on the change in environmental goods and services resulting from planned interventions into monetized values.

The information collected on planned interventions and expected environmental and social impacts, as well as the associated monetary values, were subsequently summarized into natural capital accounting templates. One reporting template was produced for each business case and one overall summary table was additionally produced to synthetize the interventions, impacts and values planned across all catchments.

SECTION A: DIRECT IMPACTS OF EACH INTERVENTION

Project managers were requested to answer questions about the interventions planned in each business case to determine anticipated intervention-specific changes in the flow of ecosystem goods and services.

1.1 Woodland

1.1.1 Woodland Creation

Carbon implications

Users identified how many hectares of woodland will be planted between 2020 and 2025, what tree species will be planted, the current land use and the woodland establishment method.

The carbon sequestration rates for tree biomass from the Woodland Carbon Code[2] were used to calculate the amount of carbon emissions avoided thanks to the intervention of woodland creation.

Table 1: Carbon sequestration rates for tree biomass

Tree species	Tree C sequestration (tCO2e/ha/yr)	Tree C sequestration range (tCO_2e/ha/yr)
Beech	1.352	1.352-16.352
Oak	1.675	1.675-17.928
Sycamore/ash/birch	9.649	9.649-24.466
Corsican pine	2.536	2.536-19.204
Douglas fir	8.732	8.732-26.224
European larch	2.804	2.804-16.056
Grand fir	8.528	8.528-23.22
Hybrid larch	6.124	6.124-17.5
Japanese larch	6.3	6.3-18.24
Leyland cypress	6.496	6.496-23.016
Lodgepole pine	0.648	0.648-16.656
Noble fir	2.873	2.872-18.008
Norway spruce	1.164	1.164-15.766
Western red cedar	5.964	5.964-20.806
Scots pine	0.194	0.194-15.668
Sitka spruce	1.268	1.268-21.95
Western hemlock	7.568	7.568-23.754

Information on the carbon emissions linked to different land cover types was obtained using the Cool Farm Tool[3] (i.e. output from TIM averaged for South West England using QGIS).

[2] https://www.forestry.gov.uk/carboncode
[3] https://coolfarmtool.org/

Table 2: Carbon emissions from different land cover types

Land Use	Carbon emissions (tCO2e/ha/yr)
Bulbs*	1.048905437
Cereals	2.361228725
Culm grassland*	0.054288713
Maize*	1.048905437
Oilseed rape	2.603636148
Other	1.048905437
Permanent grassland	1.483642211
Root crops	1.606843524
Rough grazing	0.054288713
Temporary grassland	1.718637873

* Land uses that are not defined by the Cool Farm Tool. The assumption has been made that bulbs and maize are similar to 'other' and culm grassland is similar to 'rough grazing'.

The amount of carbon sequestered was calculated by determining the difference in carbon emissions between the current land use and the future land use (i.e. woodland).

Carbon sequestered (tCO2e/yr) = (Carbon emission from current land use (tCO2e/ha/yr) – Carbon emissions from woodland (tCO2e/ha/yr)) * Hectares of woodland to be created (ha)

The carbon implications linked to the use of different woodland establishment methods were also accounted for by considering the soil disturbance carbon emission values from the Woodland Carbon Code.

Table 3: Carbon emissions from planting new woodland

Establishment method	Carbon emitted from soil (tCO2e/ha)		
	Previous land use: semi-natural	Previous land use: pasture	Previous land use: arable
Hand Screefing	0	0	0
Hand turfing and mounding	22	14.7	12.8
Forestry ploughing (Shallow turfing) and scarifying	44	29.3	25. 7
Forestry ploughing (Deep turfing and tine)	88	58.7	51.3
Agricultural Ploughing	176	117.3	102.7

The monetized value of carbon savings linked to new woodland created were calculated using the social cost of carbon for each year (BEIS, 2016).

Value of carbon saving (£/yr) = Carbon savings (tCO2e/yr) [- soil disturbance carbon emissions in 1^{st} year (tCO2e)]* Social cost of carbon (£/tCO2e)

The net present value (NPV) was determined by calculating the carbon saving for each year, assuming that benefits accrue from whenever the intervention occurs (i.e. between 2020 and 2025, we take the mid-point for this period, 2023) to 2045. To calculate the net present value, the flow of benefits was discounted using the Treasury's discount rate (3.5%).

Assumptions:
- The Woodland Carbon Code lookup table provides a range of C sequestration values for different tree species depending on forest management practices (spacing, yield length etc.) and length of time benefits accrue for. A conservative carbon sequestration value was used in the tool (i.e. the minimum values from the lookup tables).
- The Woodland Carbon Code calculator considers the carbon in tree biomass (above and below ground) and the soil carbon loss due to the disturbance caused by establishing a new woodland. But it **does not** include soil carbon accumulation rates due to woodland planting (this is expected to be added to the Woodland Carbon Code in the future).
- The Woodland Carbon Code assumes that the carbon sequestration rate does not fluctuate over time.
- That woodlands are managed without clear felling.
- If current land use is not known (which is likely as specific locations for the interventions haven't been chosen yet) then an average SW land use emissions value was used.

Implications for recreation

Given the importance of woodlands for recreation, we additionally valued the recreational benefits associated with the creation of new forested areas. To do that, we collected data on the increase in the number of visits expected as a result of interventions of new woodland creation. Then, we multiplied this amount by the value of each recreational trip to forests (which is obtained from OrVal[4], based on the average value of recreational visits to a forest in the South West, which was rounded to £3).

Recreational value linked to woodland creation (£/yr) = Average recreational value of a visit to a woodland (£/visit) * Expected change in the number of visitors per year

To obtain the net present value (NPV) recreational values were discounted by considering the Treasury's discount rate (3.5%).

1.1.2 Woodland Management

Users were also required to report any information about the expected changes in woodland management (i.e. felling, increased public access, etc.), how many hectares of woodland will be subject to change in management, and the carbon and recreation implications of these changes.

Carbon implications

The implications for the carbon balance of changes in woodland management were assessed qualitatively by asking users in each business case to report information about the expected impact (positive or negative and low-medium-high) of the intervention on carbon sequestration.

[4] http://leep.exeter.ac.uk/orval/

Implications for recreation

To calculate the change in recreational value associated with changes in woodland management, we collected data on the increase in the number of visits expected as a result of the intervention. Then, we multiplied this amount by the average value of a recreational visit to a forest in the South West, which was calculated from OrVal and rounded to £3).

Recreational value linked to changes in woodland management (£/yr) = Average recreational value of a visit to a woodland (£/visit) * Change in the number of visitors per year

To obtain the net present value (NPV) recreational values were discounted by considering the Treasury's discount rate (3.5%). We additionally assumed that the increase in recreational visits as a result of the intervention of woodland management will take place starting from 2023 to 2045.

1.2 Peatland restoration

Carbon implications

To value the carbon savings from peatland restoration, users were asked to identify how many hectares of peatland will be restored between 2020 and 2025, the year when the restoration will be completed and the current (and future) state of the peatland if the planned intervention does not take place (takes place).

The emission factors from the Peatland Carbon Code[5] were used to calculate the avoided carbon emissions resulting from the intervention of peatland restoration.

Table 4: Carbon emissions factors associated with different peatland states

State of peatland	Emission factor (tCO2e/ha/yr)
Near natural	1.08
Modified	2.54
Drained	4.54
Actively eroding	23.84

The avoided carbon emissions were valued using the social cost of carbon for each year (BEIS, 2016).

Value of carbon saving linked to peatland restoration (£/yr) = Hectares of peatland to be restored (ha) * Emissions factor (tCO2e/ha/yr) * Social cost of carbon (£/tCO2e)

The net present value (NPV) was determined by calculating the carbon saving achieved in each year, assuming that benefits accrue from the year when restoration is completed to 2045. The flow of benefits was then discounted by using the Treasury's discount rate (3.5%).

[5] http://www.iucn-uk-peatlandprogramme.org/node/325

Assumptions:
- The Peatland Carbon Code emission factors include net GHG emissions (CH_4, CO_2, N_2O, DOC and POC).
- The Peatland Carbon Code calculator assumes that restoration activities will result in a single condition category change upon completion (i.e. modified to drained).
- The Peatland Carbon Code calculator assumes that peatlands cannot achieve a fully restored state in the short term.
- The Peatland Carbon Code calculator assumes that there is not a temporal change in carbon emissions from peatlands of a given state. This assumption is made due to lack of long term monitoring data.
- The Peatland Carbon Code assumes that a near natural peatland will still have net GHG emissions. The code uses conservative numbers as there is a lack of long term monitoring data.

Recreation

Peatland restoration could have implications also on recreational visits. To infer information about the total recreational value associated with activities of peatland restoration, we collected information from users on the expected change in the number of visits to a restored peatland area. We considered £4.31 as the average value of a recreational visit to a peatland (taken from the OrVal tool).

Recreational value of a visit to a restored peatland (£/yr) = Average recreational value of a visit to a peatland (£/visit) * Change in visitor numbers per year resulting from restoration (no./yr)

To obtain the net present value (NPV), we assumed that benefits will accrue every year from the year when restoration is completed to 2045 and we discounted the resulting flow of benefits by considering the Treasury's discount rate (3.5%).

Implications for cultural heritage

We additionally asked users to provide information on possible impacts of peatland restoration in terms of cultural/ archaeological heritage. The purpose of this was to try to place a value on the preservation of cultural heritage on or close to peatland areas.

We acknowledge the difficulty of valuing the impacts of peatland restoration on cultural heritage and, where applicable, we only provided a qualitative assessment of the impacts. Nevertheless, we present below examples of secondary valuation literature focusing on the value of preserving cultural heritage.

Table 5: Examples of willingness to pay for cultural heritage

Definition of the good valued	Value (£)	Literature/Source
WTP per year (for the next 10 years) to maintain this site and keep it open to the public - Aberlemno Cross (Early Medieval standing stones). Population surveyed: general public	£3.22/person/year	Kuhfuss and Hanley (2016)[6]
WTP per year (for the next 10 years) to maintain this site and keep it open	£2.54/person/year	Kuhfuss and Hanley (2016)

[6] Laure Kuhfuss, Nick Hanley Russell Whyte (2016). Should historic sites protection be targeted at the most famous? Evidence from a contingent valuation in Scotland.

to the public – Calanais (standing stones). Population surveyed: general public		
WTP per year (for the next 10 years) to maintain this site and keep it open to the public – Mousa Broch (Iron Age round stones). Population surveyed: General public	£2.32/person/year	Kuhfuss and Hanley (2016)
WTP for new artifacts	£7.52/visitor	Willis et al. (2009)[7]

1.3. *Culm grassland*

Carbon implications

Users were also asked to provide information on any planned wet grassland/ Culm grassland management intervention. They were requested to identify how many hectares of wet grassland/Culm grassland will be restored 2020 and 2025, as well as to provide information on the current land use.

To calculate the change in carbon emissions associated with moving from a given land cover to Culm grassland, the carbon emissions linked to different land uses were calculated based on the Cool Farm Tool (i.e. output from TIM averaged for South West England using QGIS). Given that Culm grassland is not explicitly considered in the Cool Farm Tool, it was assumed that culm grassland has similar carbon emission levels as 'rough grazing'.

Table 6: Carbon emissions from different land types

Land Use	Carbon emissions (tCO2e/ha/yr)
Bulbs*	1.048905437
Cereals	2.361228725
Culm grassland*	0.054288713
Maize*	1.048905437
Oilseed rape	2.603636148
Other	1.048905437
Permanent grassland	1.483642211
Root crops	1.606843524
Rough grazing	0.054288713
Temporary grassland	1.718637873

* Land uses that are not defined by the Cool Farm Tool. The assumption has been made that bulbs and maize are similar to 'other'.

The carbon sequestered as a result of Culm grassland interventions, was calculated by determining the difference in carbon emissions between the current land use and land use with Culm grassland.

Carbon sequestered (tCO2e/yr) = (Carbon emission from current land use (tCO2e/ha/yr) – Carbon emissions from land use with Culm grassland (tCO2e/ha/yr)) * Hectares of land converted to Culm grassland (ha)

[7] Kenneth G. Willis (2009). Assessing Visitor Preferences in the Management of Archaeological and Heritage Attractions: a Case Study of Hadrian's Roman Wall. Int. J. Tourism Res. 11, 487–505

The value of reduced carbon emissions was calculated by using the social cost of carbon for each year (BEIS, 2016).

Value of carbon saving (£/yr) = Carbon savings (tCO2e/yr) * Social cost of carbon (£/tCO2e)

The net present value (NPV) was determined by calculating the carbon saving for each year, assuming that benefits accrue from whenever the intervention occurs (i.e. between 2020 and 2025, we take the mid-point, 2023) to 2045. Then, the flow of benefits was discounted using the Treasury's discount rate (3.5%).

Assumptions:
- Land use types that were not explicitly stated in the Cool Farm Tool were given carbon emission estimations based on similar land use types. Bulbs and maize were assumed to be similar to 'other' and Culm grassland was assumed to be similar to 'rough grazing'.
- If current land use was not known (which is likely as specific locations for the interventions haven't been chosen yet) then an average SW land use emissions value was used.

1.4. *Agricultural land use change*

We valued several impacts associated with interventions oriented towards the change in agricultural land cover. These include both public benefits that might arise from changes in land cover type and stocking densities (including impacts on carbon emissions or changes in cultural heritage), as well as private benefits that might arise for farmers (change in gross margins and private savings).

1.4.1. Changing agricultural land cover type

Carbon implications

To identify the change in carbon emissions associated with different agricultural land uses, we considered the carbon emission factors obtained from the Cool Farm Tool (i.e. output from TIM averaged for South West England using QGIS).

Table 7: Carbon emissions from different land cover types

Land Use	Carbon emissions (tCO2e/ha/yr)
Bulbs*	1.048905437
Cereals	2.361228725
Culm grassland*	0.054288713
Maize*	1.048905437
Oilseed rape	2.603636148
Other	1.048905437
Permanent grassland	1.483642211
Root crops	1.606843524
Rough grazing	0.054288713
Temporary grassland	1.718637873

* Land uses that are not defined by the Cool Farm Tool. The assumption was made that bulbs and maize are similar to 'other'.

The carbon saving from the land use change was calculated by determining the difference in carbon emissions between the current land use and the future land use.

Carbon sequestered (tCO2e/yr) = (Carbon emission from current land use (tCO2e/ha/yr) – Carbon emissions from future land use (tCO2e/ha/yr)) * Hectares of land use change (ha)

The value of reduced carbon emissions achieved through land use changes was calculated by using the social cost of carbon for each year (BEIS, 2016).

Value of carbon saving (£/yr) = Carbon savings (tCO2e/yr) * Social cost of carbon (£/tCO2e)

The net present value (NPV) was determined by calculating the carbon saving for each year, assuming that benefits accrue from whenever the intervention occurs (i.e. between 2020 and 2025, we take the mid-point, 2023) to 2045. The flow of benefits was then discounted using the Treasury's discount rate (3.5%).

Assumptions:
- Land use types that are not explicitly stated in the Cool Farm Tool were given carbon emission estimations based on similar land use types. Bulbs and maize were assumed to be similar to 'other'.
- If current land use was not known (which is likely as specific locations for the interventions haven't been chosen yet) then an average SW land use emissions value was used.

Implications for farmers' gross margins

We also calculated the change in farmers' gross margins related to changes in agricultural land cover. To do that we relied on the gross margin's figures published in the John Nix Pocketbook for Farm Management (2018)[8].

Table 8: farmers' gross margins from different land cover types *

land cover/change	farmers' gross margins related to land cover types (£/ha)
Bulbs	601.38
Cereals	601.38
Culm grassland	0
Maize	822
Oilseed rape	524
Other	601.38
Permanent grassland	403.15
Root crops	2070.33
Rough grazing	403.15
Temporary grassland	551.50
Not sure	601.38

* 'Bulbs', 'Other' and 'Not sure' were assumed to have the same profitability as 'cereals'. We assumed that gross margins related to 'rough grazing', 'temporary grassland' and 'permanent grassland' are all

[8] Graham Redman (2018). The John Nix Pocketbook for farm management. 48th ed. Melton Mowbray: Agro Business Consultants.

based on 'ryegrass' (used for pasture and forage). Based on https://beefandlamb.ahdb.org.uk/wp-content/uploads/2016/07/BRP-Improving-soils-for-better-returns-manual-3.pdf we assumed that 'permanent grassland' and 'rough grazing' have lower margins per ha (by a factor of 0.731) with respect to temporary grassland.

After calculating the gross margins associated with the current and future land cover type, we then calculated the difference to obtain information on the change in gross margins per ha. By multiplying this amount by the number of ha subject to the land cover change, we could get an estimate of the total change in gross margins resulting from the intervention.

Total change (-) in gross margins = (Gross margins per ha associated with current land use – Gross margins per ha associated with future land use) * Hectares of land use change (ha)

The net present value (NPV) was determined by calculating the change in gross margins from when the intervention occurs (i.e. between 2020 and 2025, we take the mid-point, 2023) to 2045 and by applying the Treasury's discount rate (3.5%).

1.4.2. Changing stocking density

Users were additional asked to indicate whether the planned interventions will aim to change stocking densities (number of livestock per type by ha) and the hectares of land over which the change will take place.

Carbon implications of changes in stocking density

We calculated the carbon emissions associated with current and future stocking densities for given types of livestock by using the carbon emission factors based on the Cool Farm Tool (i.e. output from TIM averaged for South West England using QGIS).

Table 9: Carbon emissions from different livestock types

Livestock types	Livestock emissions (tCO2e/ha/yr)
Dairy	5.33523
Beef	2.17569
Sheep	0.30452

After calculating the difference in the carbon emissions linked to current and future expected stocking densities for given livestock types, the resulting amount was multiplied by the number of hectares over which the change in livestock rates will take place.

Carbon savings (tCO2e/yr) = (Carbon emission associated with current stocking density for given livestock type (tCO2e/ha/yr) – Carbon emission associated with future stocking density for given livestock type (tCO2e/ha/yr)) * Hectares of land where the change in stocking density will occur (ha)

The value of increases of decreases in carbon emission linked to different stocking densities was calculated by using the social cost of carbon for each year (BEIS, 2016).

The net present value (NPV) was determined by calculating the carbon saving for each year, assuming that benefits will accrue from whenever the intervention occurs (i.e. between 2020 and 2025, we take the mid-point, 2023) to 2045. The flow of benefits was then discounted using the Treasury's discount rate (3.5%).

Implications for farmers' gross margins of changes in stocking density

Based on the information collected on the changes in the stocking density (number of animals/ha) before and after the intervention, as well as the number of hectares where the change should take place and the farm gross margins related to different livestock types (John Nix Pocketbook for Farm Management (2018), see figures reported below), we calculated the loss or gains in gross margins that farmers would experience as a result of the decrease or increase in stocking density.

Change in farm margins linked to a change in stocking density (£/yr) = (Stocking density associated with current land use (no/ha) – Stocking density associated with future land use (no/ha)) * Hectares of land where the change in livestock will occur (ha) * farm gross margins associated with a specific livestock type (£/ha)

For the farm gross margins, we considered the figures publishes in the John Nix Pocketbook for Farm Management (2018).

Table 10: farmers' gross margins from different livestock types

Livestock types	farms' gross margins related to livestock (£/head)
Dairy	811.17
Beef	163.67
Sheep	27.75

The net present value (NPV) was determined by assuming that the change in farm's gross margin would accrue each year from whenever the intervention occurs (i.e. between 2020 and 2025, we take the mid-point, 2023) to 2045. The Treasury's discount rate (3.5%) was then applied.

1.4.3._Changes in soil management

Users were also asked to provide information on interventions aiming to improve the management of soils and the resulting benefits in terms of increased carbon sequestration as well as private savings for farmers in terms, for example, of reduced use of inputs (nutrients) or avoided yield loss.

Carbon implications

Information on the carbon benefits of better soil management was qualitatively assessed by asking users to provide information (where available) or expert judgment regarding whether carbon emissions would increase or decrease as a result of the intervention and by how much (small, medium or high change).

Private savings

Users were asked to provide information on the benefits that planned interventions of better soil management would generate for farmers in terms of private savings. In particular, two categories of private savings for farmers were anticipated as a result of planned interventions: i) those linked to reduced fertilizers and nutrients use; and ii) those linked to reduced soil erosion. We asked users to provide data (where available) or alternatively to use their expert judgment to estimate the amount of private savings that farmers would incur per ha of agricultural land, as a result of planned interventions. Given the heterogeneity in the figures provided, the research team decided, jointly with Upstream Thinking manager Dr. David Smith, to consider the most conservative figures across all business cases. Two figures were then taken into account:

- £ 100/ha/year reflecting the private savings that farmers would incur in terms of reduced fertilizers' costs resulting from better soil management and higher income linked to greater grass yield. It was expected that better soil management could improve nitrogen's uptake (decrease nitrogen's runoff) and increase grass growth, which generates both reduced costs and higher gross margins for farmers.
- £ 33/ha/year reflecting the private savings for farmers resulting from reduced soil erosion and including both avoided yield loss and avoided operational costs.

For each of the above-mentioned categories of private savings, we asked project managers in each business case to provide an estimate of the expected number of hectares of land where private savings might take place as a result of improved soil management interventions.

For each of the above-mentioned categories of private savings, the benefits for farmers in terms of reduced costs and increased income resulting from better soil management on agricultural land, could be calculated based on the following formula:

Value of on-farm private savings (£/yr) = Soil management savings per ha (£/ha) * No. of hectares of land subject to better soil management (ha)

As a next step, we calculated the net present value (NPV) of the flow of private savings. Based on project managers' recommendations, it was assumed that savings on nutrients would accrue each year from when the intervention takes place (2020-25, we took the mid-point, 2023) to 2045. Similarly, for the benefits resulting from reduced soil erosion, project managers advised to assume that savings would happen each year for 10 years starting from when the intervention is first put in place. To calculate the net present value of the flow of private savings, we employed the Treasury's discount rate (3.5%).

1.4.4. On-farm management (cultural heritage)

We also collected information on potential impacts of on-farm management for cultural heritage.

We acknowledge that it is difficult to value the effect of changes in agricultural land on cultural heritage and therefore opted for a qualitative assessment of those impacts. In any case, we report below some examples of published studies focusing on the value of preserving cultural heritage.

Table 11: Willingness to pay studies on the value of improving cultural heritage

Definition of the good valued	Value (£)	Literature/Source
WTP per year (for the next 10 years) to maintain this site and keep it open to the public - Aberlemno Cross (Early Medieval standing stones). Population surveyed: general public	£3.22/person/year	Kuhfuss and Hanley (2016)
WTP per year (for the next 10 years) to maintain this site and keep it open to the public – Calanais (standing stones). Population surveyed: general public	£2.54/person/year	Kuhfuss and Hanley (2016)
WTP per year (for the next 10 years) to maintain this site and keep it open to the public – Mousa Broch (Iron Age round stones). Population surveyed: General public	£2.32/person/year	Kuhfuss and Hanley (2016)
WTP for new artifacts	£7.52/visitor	Willis et al. (2009)

1.4.5. On-farm measures (biodiversity)

Qualitative information was also collected from users on the expected changes in biodiversity resulting from interventions planned on agricultural land. In particular, we collected information on possible benefits in terms of pollinators, as well as planned interventions to reduce the presence of invasive species. Biodiversity is a complex and highly context-specific concept and we did not attempt to provide a monetary value for it. Therefore, we only presented a qualitative assessment.

1.4.6. New farm buildings

Carbon implications

Users were also asked to provide information on whether new farm buildings are expected to be constructed as a result of planned on-farm measures and how many tonnes of concrete are likely to be used. This information was then linked with the figure provided by Hammond and Jones (2008) regarding the levels of embodied energy and carbon in construction materials per tonnes of concrete (0.128 tCO2eq/tonne of concrete).

Carbon emissions of concrete used in construction (tCO2e) = Embedded CO2e emissions from concrete (tCO2eq/tonne of concrete) * Tonnes of concrete used (tonne)

To calculate the value of the associated change in carbon emissions, we then linked the above figure with the social cost of carbon (BEIS, 2016). Assuming that the impact on carbon are one-off, we then discounted the resulting value using the Treasury’s discount rate (3.5%).

1.4.7. Volunteering (health benefits)

Where volunteers are involved in interventions to better manage the environment, health benefits were also expected to take place. In fact, it is known that outdoor activities contribute to reduce the risks of heart attacks and other morbidities, as well as to increase mental wellbeing. This is particularly true in the case of frequent engagement in volunteering outdoor activities.

Even though it is difficult to place a monetary value on the health and mental benefits of volunteering, some calculations can be attempted (while acknowledging all the necessary limitations). To do that, we considered the concept of quality-adjusted life years (QALY), which is a measure of the state of health of a person. One QALY is equal to 1 year of life in perfect health.

In each business case, project managers were asked to provide information on the expected number of volunteer days related to the planned interventions. Information was collected on both the total number of volunteers expected to be engaged every year in each given catchment, as well as on the number of *frequent* volunteers expected to be involved in the implementation of planned interventions weekly or at least once a month. Monetized information could be obtained only for this latter.

This is because monetary figures on the health benefits of volunteering were only available for frequent volunteers, based on the study by Fujiwara et al (2013)[9]. This study follows the wellbeing valuation approach to estimate the value of an increase in a person's well-being resulting from frequent voluntary activity (weekly or at least once a month) using data on life satisfaction from the British Household Panel Survey (BHPS) for people aged over 16 years old. Based on Fujiwara et al (2013), the health benefits associated to frequent volunteering was estimated to be £3,249 per person per year, on average.

Health benefits of frequent volunteering (£/year) = Average health benefits associated with frequent volunteering activities (£/frequent volunteer/year) * Number of frequent volunteers expected to be engaged every year

The net present value (NPV) is determined by assuming that volunteering benefits would accrue every year until 2045, starting from the year when the intervention is implemented (i.e. between 2020 and 2025, we take the mid-point, 2023). To calculate the net present value of this flow of benefits, the Treasury's discount rate (3.5%) was employed.

1.4.8. Change in other habitats

Carbon implications

We additionally asked users to provide any information about expected changes in other land uses not already included in the categories presented before. In particular, we asked project managers to provide an estimate or qualitative assessment of possible changes in carbon emissions as a result of the change in land use.

[9] Daniel Fujiwara, Paul Oroyemi and Ewen McKinnon (2013). Wellbeing and civil society: estimating the value of volunteering using subjective wellbeing data. Department for Work and Pensions Working paper No 112

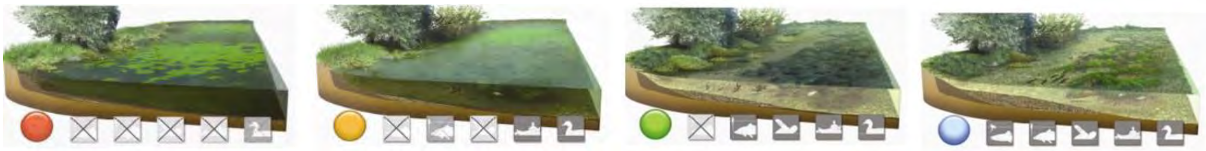
SECTION B: DOWNSTREAM IMPACTS OF INTERVENTIONS

In this section, we collected information about the possible environmental impacts that are expected as a results of the interventions planned for each business case. The main impacts considered included: water quality and related recreational impacts, as well as implications for water quantity.

2.1. Water quality (ecological condition)

We asked project managers in each business case to provide information about the cumulative (overall) impacts that are anticipated on water quality (ecological condition) as a result of the planned interventions. Water quality was classified by considering the Water Framework Directive categories, which give indications of the ecological health of a river. In this classification system, various parameters are considered, including the presence and type of aquatic plants, the extent and type of vegetation cover on bank sides, the number and types of fish species, as well as the presence of other animals like birds and possible recreational activities that can be undertaken (i.e. swimming and boating). Based on these parameters, the classification distinguishes between four main water quality categories: blue, green, yellow and red, with blue being the best water quality condition and red being the worst. To collect information about the water quality category, we considered a water quality 'slider' (shown below), based on the pictograms and categories developed by Hime et al. (2009)[10]. We additionally provided a description of the different water quality classes (reported in the Annex to this document).

Fig. 1. Pictograms used to describe the water quality categories, based on the Water Framework Directive classification



Given the heterogeneity in the responses provided by project managers in terms of the expected changes in water quality in the different business cases, the research team decided, jointly with the Upstream Thinking manager, Dr. David Smith, to adopt a uniform approach. Based on this, the most conservative estimation of water quality change was applied across all business cases. Taking all expected water quality changes reported by project managers, the most conservative estimate emerged to be a 0.6 step change (considering that a one full step change corresponds, for instance, to a change from poor to medium or from medium to good).

Recreational impacts

Changes in water quality are likely to generate substantial improvements in recreational benefits for the region.

Information on the recreational benefits associated with water quality improvements was obtained from the Outdoor Recreation Valuation Tool (ORVal). The ORVal tool is based on a sophisticated model of recreational demand for outdoor greenspace, estimated from data collected in the annual Monitor

[10] Stephanie Hime, Ian J. Bateman, Paulette Posen and Michael Hutchins (2009). A transferable water quality ladder for conveying use and ecological information within public surveys. CSERGE Working Paper EDM 09-01

of Engagement with the Natural Environment (MENE) survey (Natural England 2017) [11]. The model can be used to estimate the levels of visitation to existing or newly created greenspaces when a change in environmental quality takes place and to derive monetary measures of the value households attach to the recreational opportunities provided by those sites. This tool was developed by Day and Smith (2018)[12] at the Land, Environment, Economics and Policy (LEEP) Institute at the University of Exeter with funding support provided by DEFRA and is available at: http://leep.exeter.ac.uk/orval.

For the purposes of our research, the research team at the University of Exeter used OrVal to obtain information about the change in the number of visitors to a river (per km per year) that would occur as a result of water quality improvements. In addition, OrVal was used to obtain information on the average value per year of an additional recreational visit to a river experiencing a given water quality improvement. See Appendix 2 for a step-by-step description of how this information was calculated from the OrVal model.

To calculate the recreational value of expected changes in water quality, information was also collected from project managers. This includes: i) the expected change in water ecological condition (based on the 4-steps Water Framework Directive classification ladder) and ii) the km of river that will experience the improvement in water quality. One comment is worth regarding this latter point. To calculate the kilometers of river where water quality improvements are expected to take place in the future, we compared information provided by project managers with actual (GIS based) measurements. The actual (GIS-based) measurement was based on different datasets (OS main rivers and length of WFD rivers)[13] and it relied on the calculation of the maximum number of km of water courses within each catchment that could potentially be improved. Both actual measurement and estimations provided by project managers for each business case are reported in Appendix 3. For the purposes of our exercise, we opted for a conservative approach and, for each business case, we considered the lowest figure between the actual and estimated river length.

To calculate the aggregate recreational value of an improvement in water quality in a given business case per year, we multiplied together the following elements: i) the South-West average recreational value for a visit to a site with better water quality (£2.90/visit/year/one step-change in the water quality classification; ii) the South-West average increase in the number of visitors, resulting from the environmental improvement, (1,329 visitors/km/year for a one step-change in the water quality classification); iii) the number of km of river length where the water quality will be improved; and iv) the expected step change in the Water Framework Directive classification of water's ecological condition (taken to be the minimum reported figure of water quality change across all business cases, namely 0.6).

Recreational value of improved water quality (£/yr) = Length of river experiencing the water quality change (km) * Average number of extra recreational visits to an improved river in South West England

[11] Natural England (2017) Monitor of Engagement with the Natural Environment: Technical Report to the 2009-2016 surveys.
[12] Day, B. and Smith, G. (2018) The ORVal Recreation Demand Model: Extension Project, Land Environment, Economics and Policy Institute (LEEP), University of Exeter

[13] Datasets considered to calculate river length, include: OS main rivers GIS data. WFD river data available from the Environment Agency's 'WFD - River, Canal and Surface Water Transfer Water bodies Cycle 2' dataset (https://data.gov.uk/dataset/c5a3e877-12c3-4e81-8603-d2d205d52d7a/wfd-river-canal-and-surface-water-transfer-waterbodies-cycle-2)

per km per year (Visits/km/year/one step-change in the water quality classification) * Average recreational value of a river visit in South West England for a given water quality change (£/visit/year) * number of step changes in the water quality scale

The net present value (NPV) was determined by using the Treasury's discount rate (3.5%) and assuming that benefits accrue from whenever the water quality improvement is expected to occur (i.e. between 2020 and 2025) to 2045.

Assumptions:
- ORVal only values day trips not overnight visits.

2.1.2. Impacts on fishing recreation

Information was collected on the expected impacts of the planned interventions on fishing activities. We requested information on current levels of fishing activity, future expected levels without intervention as well as with the intervention. Users could provide information on the impact on fishing for two broad categories of fishes: coarse fishes and game fishes (salmons and trout). We asked project managers to indicate the nature of their available data on fishing activities (i.e. number of catches, visits or licenses).

To quantify in monetary terms the recreational (fishing) benefits associated with the planned water quality interventions, we considered published valuation studies (Johnston et al. 2006), providing estimates of the willingness to pay per fishing trips or catch, for different fish types.

Table 12: Willingness to pay studies on marginal value of a fish from Johnston et al (2006)[14]

Definition of the good valued	Value (£)	Literature/Source
Marginal value of a trout	$ 2.435 (mean)	Boyle, Roach, Waddington (1998)
Marginal value of a trout/salmon	$ 31.55 (mean)	Breffle et al. (1999)
Marginal value of a salmon	$ 11.29 (mean)	Cameron and Huppert (1989)
Marginal value of a salmon	$ 2.51 (mean)	Cameron and James (1987)
Marginal value of a salmon	$ 19.78 (mean)	Cameron and James (1987)
Marginal value of a trout	$ 39.77 (mean)	Cameron, Haneman and Steinberg (1990)
Marginal value of a trout	$ 1.74 (mean)	Johnson et al. (1995)
Marginal value of a brown and rainbow trout Marginal value of a rainbow trout	$1.24 (mean $ 2.58 (mean)	Johnson et al. (1989)
Marginal value of a gamefish	$ 40.99 (mean)	Kirkley et al. (1999)
Marginal value of a trout	$ 2.48 (mean)	Lee (1996)
	Average: $ 14.21	
Mean WTP for catching an additional fish (average over different types of fishes) was $14.33		

* values are in 2003 dollars. Dollar-pound conversion rate in 2003 was: 1 dollar=0.6 pounds. This means that the average mean value of an extra fish would be £ 5.6 (2003 pounds). In current values this would equal to £ 9.38 (in 2018 pounds).

To calculate the benefits associated with each additional fishing catch, we considered the average value of an additional game fish based on the literature reviewed above, namely £ 9.38 (in 2018 pound terms).

[14] Johnston, R., Ranson, M.H., Besedin, E.Y., Helm, E. (2006). What Determines Willingness to Pay per Fish? A Meta-Analysis of Recreational Fishing Values. Marine Resource Economics, Volume 21, pp. 1–32

Recreational fishing value (£/yr) = [Future no. of catches per year – No. of catches per year without the intervention] * Average recreational value of an additional fish (£)

The net present value (NPV) was determined by using the Treasury's discount rate (3.5%) and assuming that benefits would accrue from whenever the intervention is undertaken (i.e. between 2020 and 2025, we take the mid-point 2023) to 2045.

2.1.3. Recreation: Bathing Water

If interventions generated some impacts in terms of bathing water quality, it could be possible to obtain information on the expected change in recreational values associated, by using the Outdoor Recreation Valuation Tool (ORVal). Based on OrVal, the recreational value of a stepwise increase in bathing water quality is worth £5.25.

We asked users to indicate the existing and expected bathing water quality in the different locations in the business cases. To do that, we presented some 'sliders' (as displayed below) with four main bathing water quality categories: excellent, good, sufficient and poor. These categories relied on the Bathing Water Directive (BWD) classifications, which summarizes information on the hygienic quality of the bathing water by measuring the level of faecal bacteria in the water. Bathing waters with high concentrations of these bacteria are at risk of also having pathogens present. These can cause diseases involving fever, sickness and diarrhoea, which can be bad for the health of bathers.

Figure 2. Pictograms for the bathing waters quality classification, based on the Bathing Water Directive

To value the expected recreational impacts of changes in bathing water quality, information was collected from project managers also to estimate the increase or decrease in the number of visitors as a result of planned interventions.

2.1.4 Flood risk reduction

Valuing flood risks will be a difficult task. Both in terms of forecasting expected flood risk reductions resulting from interventions and in terms of putting a monetary value on the risk reduction that could be achieved. For this reason, we recorded only qualitative information on the impacts of interventions on flood risk. Nonetheless we provide some examples of useful value estimates that could be used to attempt to calculate the monetary benefits of flood risk reductions based on the literature:

Table 13: willingness to pay studies on value of flood risk reduction

Definition of the good valued	Value (£)	Literature/Source
WTP per household per year to reduce the risk of internal flooding event	£127, 798	SWW
WTP per household per year to reduce the risk of external garden flooding event	£6,691	SWW
WTP for: - Reducing the flood probability by 1% - insuring against the risks associated with an increase in inundation depth by 10 cm - having an insurance covering not only home content but also the building - having an insurance covering not only home content but also evacuation - having an insurance covering not only home content but life insurance	€54.357/household/month €0.33/household/month €14.961/household/month €14.677/household/month €0 extra/household/month	Brouwer and Schaafsma (2013)[15]

Given that most of the information provided by project managers on flood risk was qualitative, no valuation exercise was attempted and in the natural capital accounts we included only a description of expected qualitative impact in terms of flood risk.

2.1.5. Low flows management (visual amenity value)

Reducing low flow problems in some river stretches could be beneficial for recreational angling, for the ecology of rivers and, overall, for the scenic (amenity) value of the site. However, it is a difficult aspect to value.

We did not attempt to calculate the monetary value of reducing low flow problems. Nonetheless we provide some useful references from the literature on existing studies dealing with the value of low flow reduction:

Table 15: willingness to pay studies on value of water low base management

Definition of the good valued	Value (£)	Literature/Source
WTP to improve flow conditions in South West rivers (Allen, Upper Avon, Meavy, Otter, Piddle, Tavy, Wyle)	£0·076/user/mile of river £0·0435/non-user/mile of river	Willis and Garrod (1999)[16]
WTP to maintain current flow levels WTP to improve current flow levels	£7.16/household/year £4.85/household/year	Garrod (1996)

Given that most of the information provided by project managers on base flow management was qualitative, no valuation exercise was attempted and in the natural capital accounts we only included a description of expected qualitative impact in terms of flood risk.

[15] Roy Brouwer & Marije Schaafsma (2013). Modelling risk adaptation and mitigation behaviour under different climate change scenarios

[16] Willis and Garrod (1999). Angling and recreation values of low-flow alleviation in rivers. Journal of Environmental Management. 57(2). 71-83.

Annex 1. Description of the water quality categories, based on the Water Framework Directive classification

Key

Excellent

Aquatic plants: no algae; presence of water plants; good clarity
Bank-side vegetation: Phragmites australis (Reed). Where Found: form beds on river banks. Rorippa nasturtium (Water cress). Where Found: shallow flowing water, halfimmersed. Gyceria sp. (Sweet-grass). Where Found: By shallow water. Salix sp. (Willow). Where found: on land. Turf. Where found: on land.
Fish species: Mostly game fish with some coarse fish
Common birds present
Recreational activities possible: swimming and boating.

Good

Aquatic plants: Greater amount of aquatic plants taking up more of the open space; Slight increase in water turbidity
Bank-side vegetation: Phragmites australis (Reed). Rorippa nasturtium (Water cress). Gyceria sp. (Sweet-grass). Salix sp. (Willow). Turf
Fish species: Virtually no game fish more coarse fish
Common birds present
Recreational activities possible: swimming and boating.

Medium

Aquatic plants: Less aquatic plants with increases in algae; further increase in turbidity and green due to the water, Small number of algal mats.
Bank-side vegetation: Phragmites australis (Reed) Salix sp. (Willow) Turf (increase in prominence)
Fish species: Virtually no game fish, less coarse fish
Common birds present
Recreational activities possible: boating, but not swimming.

Poor

Aquatic plants: Large degree of siltation; Turbid water with a brown hue; Algal mat covering the substrate
Bank-side vegetation: Salix sp. (Willow) Turf (increase in prominence)
Fish species: No fish
Common birds' number reduced
Recreational activities possible: no swimming, no boating

Annex 2. Detailed descriptions of the steps taken to calculate information about the additional recreational visits (per km/unit of water quality increase/year) and value for each additional recreational visit to an improved river (per unit of water quality increase/year).

We started by taking the 'main' rivers in Devon & Cornwall as identified by the Ordnance Survey. Then, we created a 1km grid over the same area and selected out cells through which those rivers flowed. The resulting river cell network had 1201 cells.

By means of ORVal greenspace maps, we identified recreation parks and paths that provided access to those same rivers. There were 642 of those, concentrated in just 365 of the 1201 1km river cells. Clearly not all 1km sections of river in the region provide access for recreation.

Using the ORVal model, for each of those sites, we calculated the impact of improving river quality at that site from its current quality to good/excellent quality (note that 98 of the 642 recreation sites were already at the high water quality level so experienced no change). The outcome of those individual site improvements aggregated across all sites was an increase in annual visits of 3.193 million and an increase in welfare of £9.256 million (4,947 extra visits and £14,418 extra value per year per site).

To move from those site-based figures to per km numbers, we first divided the aggregate figures by 365, that is to say, by the number of 1km squares containing recreation sites. Accordingly, the average 1km river recreation square would receive 8,748 extra visits and generate £25,359 extra value from improving water quality to good/excellent status.

However, given the improvements in the SWW business plan could impact on any stretch of river, it would be wrong to assume that each 1km cell improved would yield those benefits. Rather we assume that a 1km improved could be any of the 1,201 river cells giving a likelihood of improving a location with recreation access as 365/1201. Scaling the visits and welfare values by that factor we end up with a best guess of 2,659 extra visits and £7,707 extra value from improving a randomly chosen 1km stretch of river.

Rather than low versus high quality, the data we received from the partners is based on a 4 point scale. If we make the assumption that the low versus high information used in the ORVal model is (on average) a 2 point movement up that scale, then we need to make one more adjustment to our figures to get numbers per unit of the quality scale. Accordingly, dividing through by 2 gives our final result:

- Additional recreation visits per km or river improved: 1,329 per year per unit of quality increase;
- Additional welfare value per km or river improved: £3,854 per year per unit of quality increase
- Equivalently; welfare value per additional visit: £2.90 per year per unit of quality increase

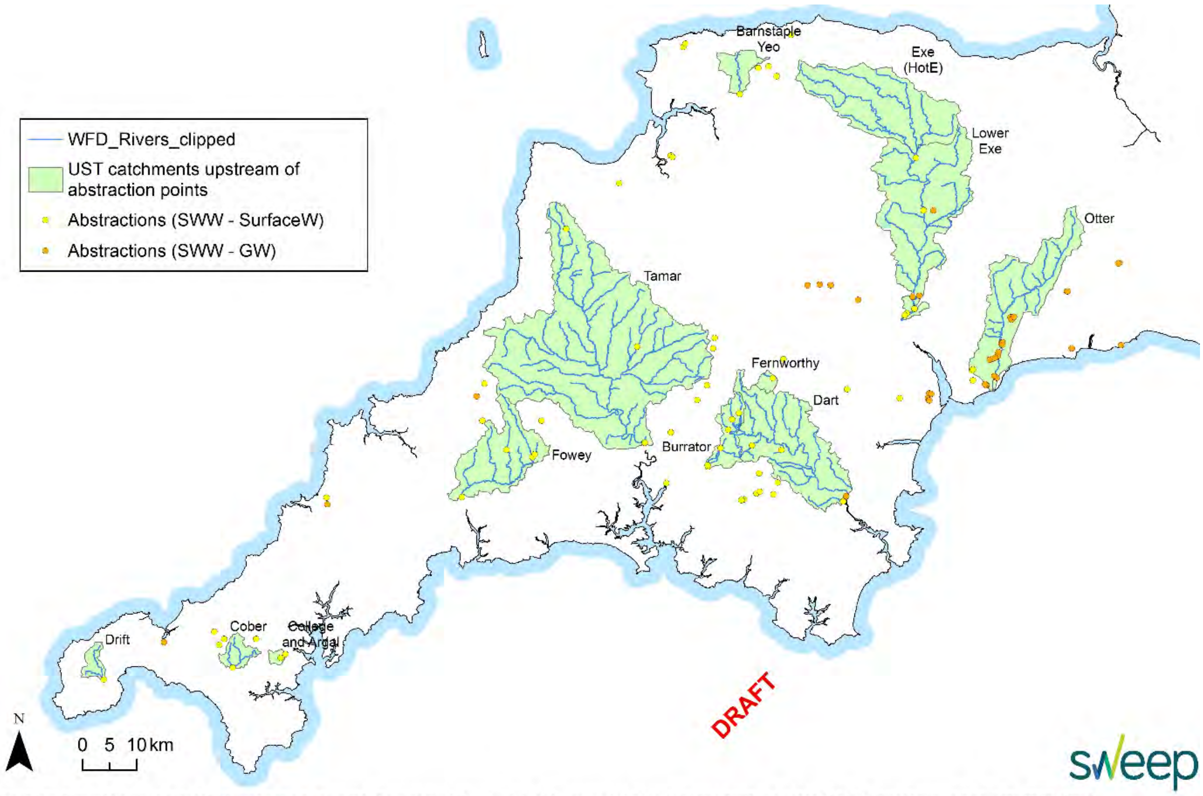
Annex 3. Information on actual and estimated (by project managers) km of river length in each catchment that could be subject to water quality improvements.

Acknowledgements: For the calculation (and mapping) of the km of river length subject to water quality improvements, we acknowledge the work of Dr. Donna Carlesss and Dr. Amanda Robinson, SWEEP Impact Fellows at the Department of Geography, University of Exeter.

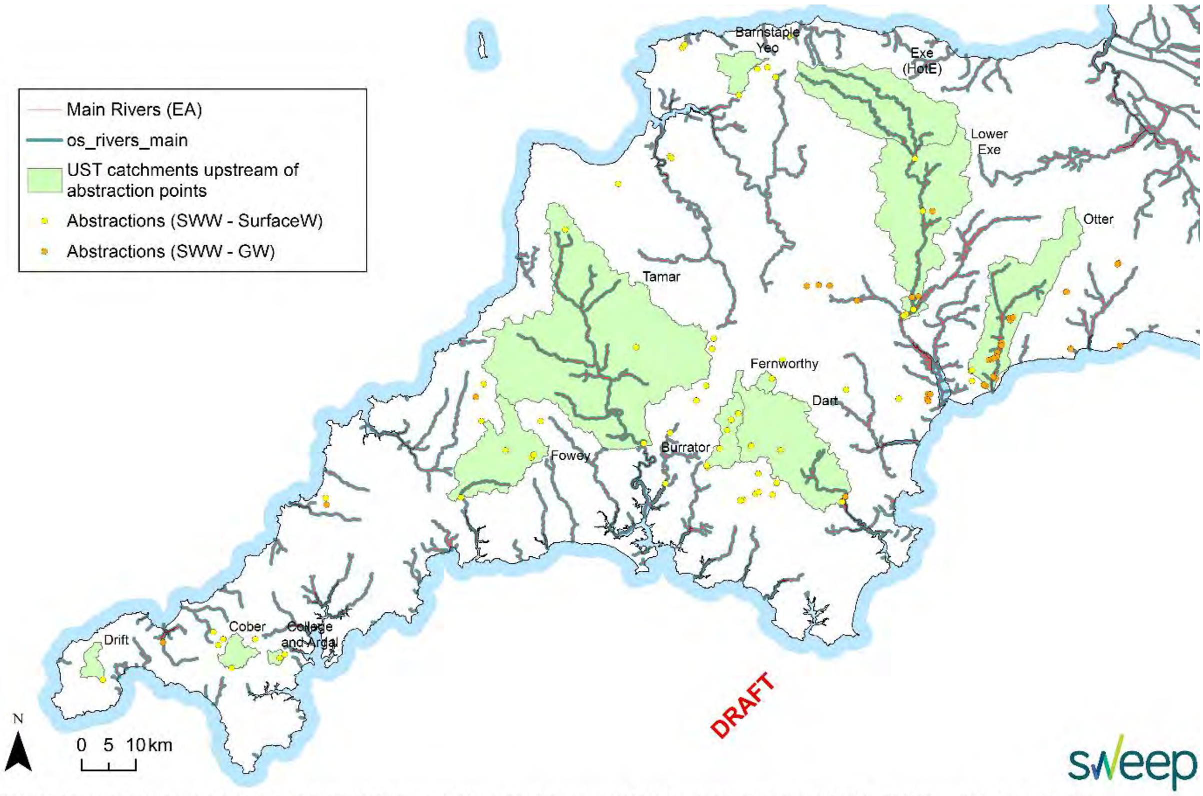
Name of the business case	OS main river	WFD river	Project managers' estimations
Argal & College	0.00	0.00	not provided
Barnstaple	0.00	11.05	20
Burrator	0.00	56.06	not provided
Cober	0.00	18.61	not provided
Dart	29.17	206.95	45
			30
Drift	0.00	12.54	not provided
Exe	78.24	165.13	45
			40
Fernworthy	0.00	2.89	2
Fowey	12.06	80.68	40
Headwaters of Exe	77.88	132.68	not provided
Otter	64.43	111.65	20
			5
Tamar	200.30	496.93	70
			40

Note: in the biggest catchments (Tamar, Dart, Exe, Otter) multiple project managers are involved, even though they operate in different locations within the catchment. What project managers have reported is the expected length of water courses subject to water quality improvements in the portion of the catchment where they are involved.

Below we also report the maps showing the length of river subject to improvement in each catchment, based on the WFD river data and the OS main rivers' data.



WFD_Rivers_clipped
UST catchments upstream of abstraction points
Abstractions (SWW - SurfaceW)
Abstractions (SWW - GW)
Barnstaple Yeo
Exe (HotE)
Lower Exe
Otter
Tamar
Fernworthy
Dart
Burrator
Fowey
Drift
Cober
College and Argal
DRAFT
N
0 5 10 km



Main Rivers (EA)
os_rivers_main
UST catchments upstream of abstraction points
Abstractions (SWW - SurfaceW)
Abstractions (SWW - GW)
Barnstaple Yeo
Exe (HotE)
Lower Exe
Otter
Tamar
Fernworthy
Dart
Burrator
Fowey
Drift
Cober
College and Argal
DRAFT
N
0 5 10 km

sweep
Tool information

SWW Upstream Thinking Portal – Decision Support Tool. Description of Contextual and Evaluation Data Layers.

Published November 2022

Authors: Kitch, J. and Jackson, B.

South West Water
Devon Wildlife Trust
Cornwall Wildlife Trust
FWAG Farming & Wildlife Advisory Group
Natural England
Westcountry Rivers Trust
swlakestrust
South West peatland Partnership

Introduction

The South West Water **Upstream Thinking Decision Support Tool (DST)** was developed in 2022 and designed to be used alongside the **SWW Upstream Thinking Portal**.

Both the Portal and the DST were developed under the NERC-funded SWEEP project 'Whole Catchment Water Management – phase 2'. Details about this project can be found on the SWEEP website at: https://sweep.ac.uk/portfolios/whole-catchment-water-management-2/

The DST is comprised of a suite of **Contextual and Evaluation Data Layers** accessible through ArcGIS Pro and was developed by:

- An academic team from the University of Exeter funded by the SWEEP project – Jess Kitch, Dr Ben Jackson, Dr Donna Carless and Prof Richard Brazier.

- In collaboration with South West Water and Upstream Thinking Delivery Partners – Cornwall Wildlife Trust, Devon Wildlife Trust, Farming and Wildlife Advisory Group (Southwest), Natural England, Westcountry Rivers Trust, South West Lakes Trust and the South West Peatland Partnership.

The **Upstream Thinking Programme (UST)** is an award-winning catchment management scheme launched in 2010 by South West Water. The programme, which applies natural landscape-scale solutions to improve water quality and supply, is funded by South West Water and delivered in collaboration with regional environmental and conservation charities.

The **Upstream Thinking Portal** was designed for UST Delivery Partners to record interventions and activities delivered as part of the Upstream Thinking Programme. The portal uses the ArcGIS Online platform and is only accessible to SWW and the UST Delivery Partners. Details of the Portal and its Instruction Manual are located at: https://sweep.ac.uk/ust-portal/

Objectives

The Decision Support Tool 'Contextual and Evaluation Data Layers' are designed to help UST Delivery Partners and SWW improve management within catchments by being better informed about the landscape and natural processes in each catchment. With the production of these datasets, and the move to ArcGIS Pro, it is hoped that the DST tool will become easier to use and can be passed on to new partners in the future.

Initial meetings were held with each partner organisation to establish the desired datasets for the development of the DST. Partners were consulted from the start, as the tool being developed is for them to use and to continue to improve water catchment management in the South West.

Data sets produced for the Contextual and Evaluation Data Layers of the UST Decision Support Tool

Table 1. Data sets included in the Decision Support Tool designed to complement the SWW UST Portal

Dataset name	Date of data	Date accessed	Accessed from
WFD data for rivers and canals	Updated May 2022	Aug 2022	https://environment.data.gov.uk/DefraDataDownload/?mapService=EA/WFDRiverCanalAndSWTWaterBodiesCycle22019&mode=spatial
Crome	Revised January 2021	Oct 2022	https://www.data.gov.uk/dataset/be5d88c9-acfb-4052-bf6b-ee9a416cfe60/crop-map-of-england-crome-2020
Scheduled monuments	March 2018	Oct 2022	https://historicengland.org.uk/listing/the-list/data-downloads
EA flood risk	August 2022	Sept 2022	https://environment.data.gov.uk/DefraDataDownload/?mapService=EA/FloodMapForPlanningRiversAndSeaFloodZone2&Mode=spatial
Living England habitat map	Updated Sept 2022	Sept 2022	https://naturalengland-defra.opendata.arcgis.com/datasets/Defra::living-england-habitat-map-phase-4/explore?location=52.812158%2C-2.489781%2C7.00
Ancient woodland	July 2019	Sept 2022	https://naturalengland-defra.opendata.arcgis.com/datasets/a14064ca50e242c4a92d020764a6d9df_0/explore?location=52.997084%2C-3.426194%2C8.20
SSSI	April 2017	Oct 2022	https://naturalengland-defra.opendata.arcgis.com/datasets/f10cbb4425154bfda349ccf493487a80_0/explore?location=52.799987%2C-2.496337%2C7.00
Land cover (SCIMAP)	2015	Oct 2022	https://catalogue.ceh.ac.uk/documents/0255c014-1630-4c2f-bc05-48a6400dd045
SCIMAP	Feb 2016	Nov 2022	https://scimap.org.uk/x64-scimap-for-saga-gis-february-2016-2/
LiDar	July 2013	Aug 2022	https://catalogue.ceh.ac.uk/documents/e2a742df-3772-481a-97d6-0de5133f4812
LiDar EA	Updated Oct 2022	Sept 2022	https://environment.data.gov.uk/DefraDataDownload/?Mode=survey

The datasets listed in the Table 1 have been clipped to each catchment to provide the specific information for that site. The above LiDar data was also collected for use in the production of SCIMAP erosion risk maps and the production of slope maps for each catchment.

The LiDAR data was collected from various sources due to the poor quality of data for some sites and from certain providers. The Lidar data was collected from the EA (freely available), as well as UK CEH and CEDA. Due to the nature of CEDA, only the end processed product can be shared with the partners and not the raw data. The SCIMAP model (run in SAGA GIS) was provided by Sim Reaney of Durham University, this is a freely accessible model. For this project the February 2016 version of SCIMAP was used. This model requires three data inputs: elevation, rainfall and land use. Rainfall data was acquired from CEDA and the HadUK dataset was used. Land use datasets were freely acquired from UK CEH.

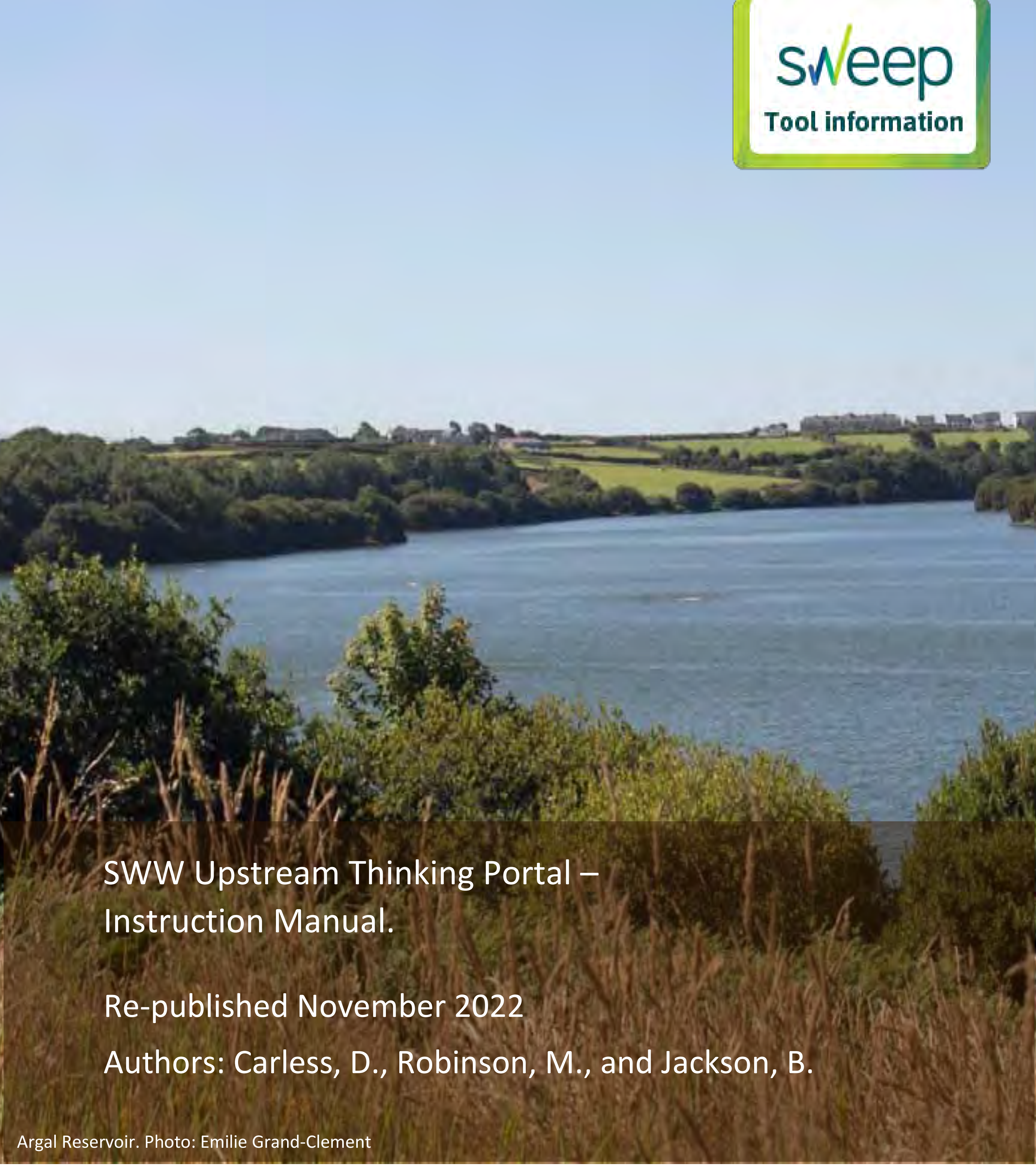
Datasets for flow pathways and sub-catchments have been produced using elevation data and an ArcGIS tool called Taudem. This tool is freely available from the Utah State University hydrology research group. The tool uses elevation data to produce flow pathways, stream order and sub-catchments. Both flow pathways and sub-catchments have been produced at a large scale and fine scale, as asked for by the partners. Although, some of the LiDar data will not be accessible for the partners, the datasets produced from the LiDar data will be.

Datasets will be available to partners via ArcGIS pro. Partners will be able to add the datasets to individual projects via the catalogue or via the 'add shapefile' or 'add raster'. Once the datasets are in a project they can be used and edited by the partners and included alongside data produced by the organisation. The datasets can also be layered to assist in evaluating sites.

Contact

For more details or queries please contact:

- Jess Kitch J.Kitch@exeter.ac.uk
- Centre for Resilience, Environment, Water and Waste, University of Exeter https://www.exeter.ac.uk/research/creww/



sweep Tool information

SWW Upstream Thinking Portal – Instruction Manual.

Re-published November 2022

Authors: Carless, D., Robinson, M., and Jackson, B.

Argal Reservoir. Photo: Emilie Grand-Clement

South West Water | Devon Wildlife Trust | Cornwall Wildlife Trust | Farming & Wildlife Advisory Group FWAG | Natural England | Westcountry Rivers Trust | swlakestrust | South West peatland Partnership

What is Upstream Thinking?

The Upstream Thinking Programme (UST) is an award-winning catchment management scheme launched in 2010 by South West Water. The programme, which applies natural landscape-scale solutions to improve water quality and supply, is funded by South West Water and delivered in collaboration with regional environmental and conservation charities (Cornwall and Devon Wildlife Trusts, the Farming & Wildlife Advisory Group SouthWest, Natural England and Westcountry Rivers Trust).

Upstream Thinking aims to ensure potential sources of pollution are prevented from entering surface waters, thus reducing the ongoing level of treatment and associated chemicals and energy required to deliver clean and safe drinking water. The programme supports farm advisers who work closely with landowners to advise on water friendly farming practices. Each farm receives a detailed and individually tailored farm plan, which outlines opportunities for change and the protection of land and water through soil, nutrient and pesticide management. Capital grants are provided to support the delivery of a broad range of interventions to foster change, from watercourse fencing to manure stores, greatly reducing the risk of pollutants entering rivers by directly intercepting the pathways of nutrients or sediment. Good soil husbandry and protection is also fundamental to water quality protection. UST therefore also offers soil testing to understand and plan nutrient applications, detailing steps to reduce the risk of erosion and mobilisation and recognising issues such as compaction[1].

The scheme now works across 18 strategically important drinking water supply river catchments and reservoirs in Devon and Cornwall delivering 16 programmes of water quality improvements and 5 investigation programmes aimed at identifying sources of water quality deterioration in those catchments.

Why it matters?

Ofwat – the economic regulator for the water industry – ensures that the price and service delivered by water companies is fair for customers. To do this, every 5 years the industry goes through a Price Review. This process controls the amount water companies can charge for their services, protecting consumer’s interests but also ensuring that the water companies have enough money to finance their functions (water and sewerage services). Ofwat also ensures that other legal obligations of the water companies are met including environmental and social duties.

As part of the process Ofwat requires the Environment Agency (as environmental regulator) and Natural England to write to water companies outlining the obligations and expectations for the water industry during the price review period 2020-2025 (PR19). To understand how best to protect and enhance the natural water environment, they work together to develop a Water Industry National Environment Programme (WINEP). The WINEP represents a set of actions that the water company must complete within the Price Review period. The measures outlined and agreed through the WINEP provide an opportunity for the water company to develop innovative approaches to meet environmental outcomes and enhance the resilience of these ecosystems, which should benefit the customer, community, the environment, and natural capital.

The need for evidence

Ofwat sets service targets ('performance commitments') for the PR period. This encourages the companies to deliver on the objectives agreed. Most of the water companies' performance commitments have rewards and penalties ('outcome delivery incentives (ODIs)') associated with them. At South West Water the agreed ODI is 50,000 hectares of land actively engaged for water quality or biodiversity enhancement. To measure success, progress towards achieving this target is reported to Ofwat and the Environment Agency and over achievement of this performance delivery target could lead to a business reward.

In addition to reporting to Ofwat and the EA, SWW have monthly and quarterly internal reporting and audit requirements to track progress towards achieving business planning targets and for benchmarking natural capital accounting[2].

Finally, each of the UST Delivery Partners have developed implementation plans for the catchments that they work in. These plans outline actions and measures that they hope to achieve, and which are selected to ensure delivery of the key investment outcomes, in particular contributions to the cumulative total hectarage of water quality and biodiversity enhancement. To keep track of progress towards these targets appropriate and detailed information must be recorded.

How did SWEEP get involved?

Funded by the Natural Environment Research Council (NERC), the South West Partnership for Environmental and Economic Prosperity (SWEEP) is a collaborative initiative that aims to deliver economic and community benefits to the South West, whilst also protecting and enhancing the area's natural resources. Through partnership working with industry and the community, SWEEP develops bespoke tools and solutions that aid decision-making and support the management of our natural environment.

During the PR planning process, it was identified that in order to provide evidence of achievements and consistency in reporting a new method for recording UST activity was required. The SWEEP Whole Catchment Water Management project worked with UST Delivery Partners and SWW to develop a new online recording portal to log activities and measures delivered and to track progress towards targets.

This SWEEP project was delivered b:

- an academic team from the University of Exeter – Dr Donna Carless, Dr Mandy Robinson, Dr Ben Jackson, Jess Kitch and Prof Richard Brazier.
- Working in collaboration with project partners – South West Water, Cornwall Wildlife Trust, Devon Wildlife Trust, Farming and Wildlife Advisory Group South West, Catchment Sensitive Farming (Natural England), Westcountry Rivers Trust, South West Lakes Trust and South West Peatland Partnership.

Next steps

Under the SWEEP Whole Catchment project, the UST Portal was developed further in collaboration with the UST delivery partners and SWW. In 2022 partners South West Lakes Trust and South West Peatland Partnership were added to the tool.

It will continue to be maintained and supported within the Centre for Resilience in Environment, Water and Waste (CREWW) at the University of Exeter https://www.exeter.ac.uk/creww/.

To find out more please contact – Donna Carless (D.Carless@exeter.ac.uk).

The UST Portal Instruction Manual

This Instruction Manual has been written for the UST Delivery Partners to explain how to use the Upstream Thinking Portal for recording interventions and activities delivered via the Upstream Thinking Programme. The portal was developed by the University of Exeter, SWEEP Whole Catchment Management for Water Quality project (https://sweep.ac.uk/), in collaboration with SWW, members of the WRT Evidence Team and the UST Delivery Partners (CWT, DWT, FWAG, NE and WRT). The portal uses the ArcGIS Online platform and is only accessible to SWW and the UST Delivery Partners.

Tab guide and instructions

The UST Portal is divided into tabs. Each tab has a different set of purposes/functions and underlying datasets. These are listed below, with page numbers for each tab:

Introduction

Aim of the Portal

The overall aim of the portal is to record engagement activities and interventions undertaken as part of Upstream Thinking phase 3 (UST3). Broadly speaking, the portal captures what has happened and where. Data is input by the UST3 Delivery Partners/designated users.

Portal platform

The UST Portal has been developed in ArcGIS Online. GIS means Geographic Information System. GIS is a framework for gathering, storing and analysing spatial (geographic) data. This means that the data contains locational information and can be visualised in maps. GIS data is stored in layers that incorporate geographical features and tabular information (Attribute tables, which are similar to a table in an Excel spreadsheet). The portal captures and stores information in GIS layers.

Users are able to input, view, edit and extract data using the platform built in ArcGIS Online.

Each delivery partner has their own version of the portal, ensuring that they can only see their own data.

Before you enter data into the portal you must ensure that the data subject (the farmer/landowner) has been issued with a copy of the Joint Controller Privacy Notice.

Categories of data captured by the portal

The portal is designed to capture five main categories of data relating to UST3, as follows:

1. Land unit data – information about the land units (often farms) participating in UST3. This includes details such as size, location and type of land unit (e.g. farm, community land, SWW land), and in the case of farms, some information about the farm business, such as type of farm, crops grown, animals kept.

   Names and contact details of farmers or other land managers or owners are NOT collected in the portal.

2. Land unit engagement data – information about the level of engagement as part of UST3, such as number of visits, whether advice has been given by the UST3 Delivery Partner to the land manager etc.
3. Interventions data – information about the specific measures, changes in land management or advice given as part of UST3. Details collected here feed into the SWW monthly reporting items.
4. UST3 active land data – a record of the areas of land (fields) under active management as part of UST3. This refers to land areas/fields that have had physical interventions undertaken on them or have had a change in management practices as a result of the UST3 program. Active areas collected here contribute to the ODI area reporting item.
5. Catchment-scale engagement data – information about UST3 engagements that need to be collected and reported at the catchment scale. Examples include the following indicators, per catchment: number of farms contacted (including unsuccessful contacts that do not result in participation in UST3); number of WTW visits; number of pesticide amnesties; volume (liquid) and mass (solid) of pesticides disposed of in amnesties.

Data Entry: Pop-ups, Survey123 and compulsory questions

As you work through the tabs in this portal there are numerous areas where you will enter data within Survey123 forms or within 'pop-up' windows. Some questions within these data entry functions are compulsory so you will not be able to move on to the next question until data is entered.

Wherever possible, to aid data entry, we have provided drop-down choices for you to select from. At times questions will be restricted to single answers, in other places multiple choice answers can be given. These rules will already be set. If you answer 'Other' to a question you will be provided with a text box to provide additional detail.

When you select an answer to certain questions filters are applied to the questionnaire so that you are asked other relevant questions or, questions that are now irrelevant (based on your previous answer) are not asked.

It is important to follow the instructions as the answers may determine whether a value (a count or an area/length) filters though into the reporting element of the portal.

Whether an item or an area/length contributes to a reporting item may also be determined by the 'Driver' that you allocate. It is therefore essential that when asked, you tick the correct (and at least one) driver (e.g. Biodiversity, NFM, etc) (See Appendix for more information on Drivers).

Finally, where date information is requested it is important that it is provided accurately. Not all activities and interventions require dates but for those that do and where asked 'date land became active' failure to enter an accurate date will result in areas not feeding into reporting or items not appearing in filtered outputs.

Terminology: Land unit

For the purposes of the UST3 Portal, we use the term 'land unit' to refer to an area of land that is managed as a whole by a particular 'land manager' that is being engaged as part of UST3. A land unit does not need to be contiguous, it can be made up of nonadjacent land parcels / land polygons / fields.

A land unit could be a farm, in which case the 'land manager' is the farmer. A 'land unit' is not necessarily the same as a land holding and often won't be. For example, there are large land owners / estates that have multiple separate farmers / farm managers / tenants. Therefore, a single land holding could comprise multiple land units that are each managed by different farmers. When an individual farmer is being engaged in UST3, the area of land that we might expect to influence would be the area that they farm/manage, and hence it is this area of land that we want to identify as a single land unit, regardless of whether this is part of a larger land holding.

Alternatively, a land unit could be a small holding, or it could be an area of land that is managed by a community group. Or it could be a parcel of SWW owned land. In this case, the 'land unit' might be a parcel of land associated with a specific reservoir. The unit of land would certainly not be the whole of SWW's land holdings, just the specific parcel of land that is engaged in UST3.

Sometimes, a land unit engaged in UST3 may be an area of common land.

> **Terminology: GIS attribute table and attribute-fields vs farm-fields**
>
> The GIS data layers captured through the UST Portal have two key components: a component that defines the geometry of geographic features such as farms or interventions, and tabular information about those features, known as an attribute table.
>
> In ArcGIS, columns in the attribute table are known as fields. To avoid confusion between GIS fields and 'real' fields on farms, we refer to the former as attribute-fields and the latter as farm-fields.

> **See Appendix for Glossary of Terms and a full Lists of Drivers and Interventions.**

Land Unit Engagement tab

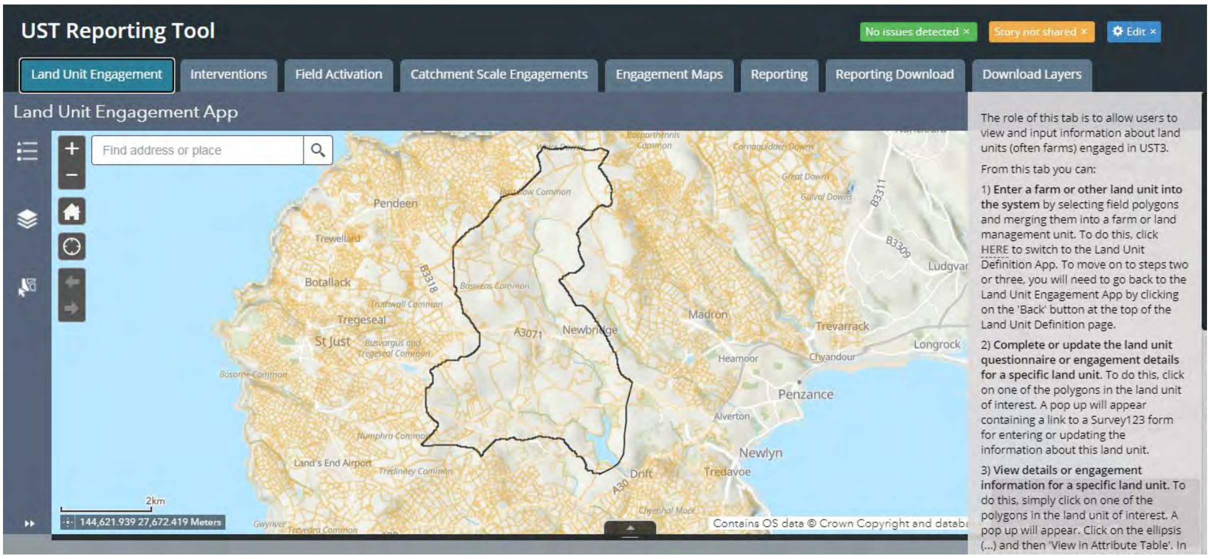


Figure 1: Full screen view of UST Reporting Portal. The Land Unit Engagement tab is active showing the Land Unit Engagement App.

Tab summary

The role of this tab is to allow users to view and input information about land units (often farms) engaged in UST3. The content of the main page of this tab is an embedded web app, called the Land Unit Engagement App (see Figure 1).

From this tab you can:

1) Enter a farm or other land unit into the system by selecting field polygons and merging them into a farm or land management unit.
2) Complete or update the engagement details or land unit questionnaire for a specific land unit.
3) View details or engagement information for a specific land unit.

The land unit engagement details include the following questions/information:

- Was this land unit engaged in UST1?
- Was this land unit engaged in UST2?
- Date first visited by Partner as part of UST3
- Date of most recent visit
- Number of pre-advice visits
- Number of advice-giving or implementation visits
- Number of maintenance or follow-up visits
- Engagement status for UST3 (engaged or not engaged)
- Has a plan/verbal advice been given to the farmer/land manager?
- Date advice/plan given
- Has any of the land in this unit come under active management?
- Date any of the land in this unit first became active

Delivery Partners will therefore need to re-visit this tab as engagement with a Land Unit progresses, leading to a change in any of these details.

The land unit questionnaire also asks for details about the land ownership (e.g. tenancy or freehold), type of land (e.g. farm, community land, SWW land) and other general details such as area of different habitat types and whether any agri-environment schemes are in place on the land unit. Several of the questions are only relevant to farms and so can be skipped (left blank) if not relevant. The land unit questionnaire can be filled in in one go if all the necessary information is available, or it can be completed in stages as additional information becomes available (e.g. resulting from a farm visit).

Tab instructions

From this tab you can:

1) **Enter a farm or other land unit into the system by selecting field polygons and merging them into a farm or land management unit.**

What does this actually mean? On the Land Unit Engagement tab, the Land Units GIS layer is visually represented in the map by lots of polygons, the boundaries of which often match up with farm-fields in real life. If a land unit is 'in the system', then all the relevant polygons will be linked to the same land unit record. In other words, all the polygons in a land unit will be represented by a single record (row) in the Land Unit layer's attribute table. Each row/record in the attribute table has a unique, system defined OBJECTID. The multiple polygons that make up a single land unit are all part of the same 'object' and therefore share a single OBJECTID.

How can I tell if my land unit of interest is already in the system? Find your area of interest and then zoom in until you can see the polygons that make up the Land Units layer. Click on one of polygons that you would expect to make up the land unit. If the polygon is already part of a land unit in the system, then the relevant polygons will be outlined/highlighted in blue (see Figure 2).
Tip: If you have selected a land unit and there are several land units close to the point that you clicked, you can use the arrow button on the top right of the pop-up to scroll through the other potential land units and visually check which fields/parcels make up each land unit. 

This step will not be necessary for delivery partners who have provided their own pre-defined land units / farm boundaries. However, before proceeding to step 2, the user should check that their land unit of interest is as it should be (i.e. comprises the correct farm-fields).

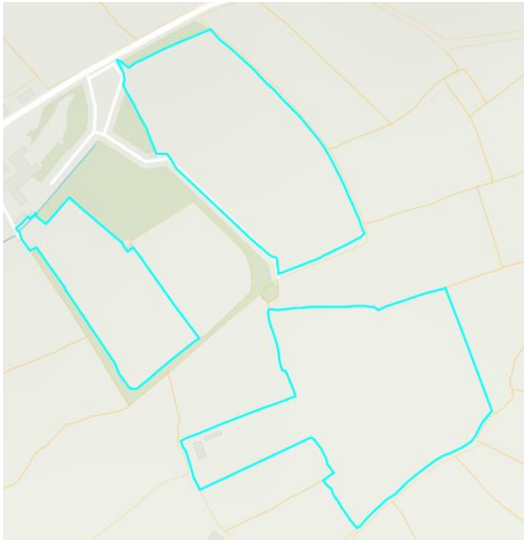


Figure 2. Example of a land unit represented in the Land Unit Engagement tab. Clicking on one polygon in the unit results in all polygons in that unit being outlined in blue.

Step-by-step guide: Enter a farm or other land unit into the system by selecting field polygons and merging them into a farm or land management unit.

In the Land Unit Engagement tab, look to the grey panel on the right (Figure 1) and click where it says '…click **HERE** to switch to the Land Unit Definition App'. The Land Unit Definition App opens in a new window. (See Figure 3).

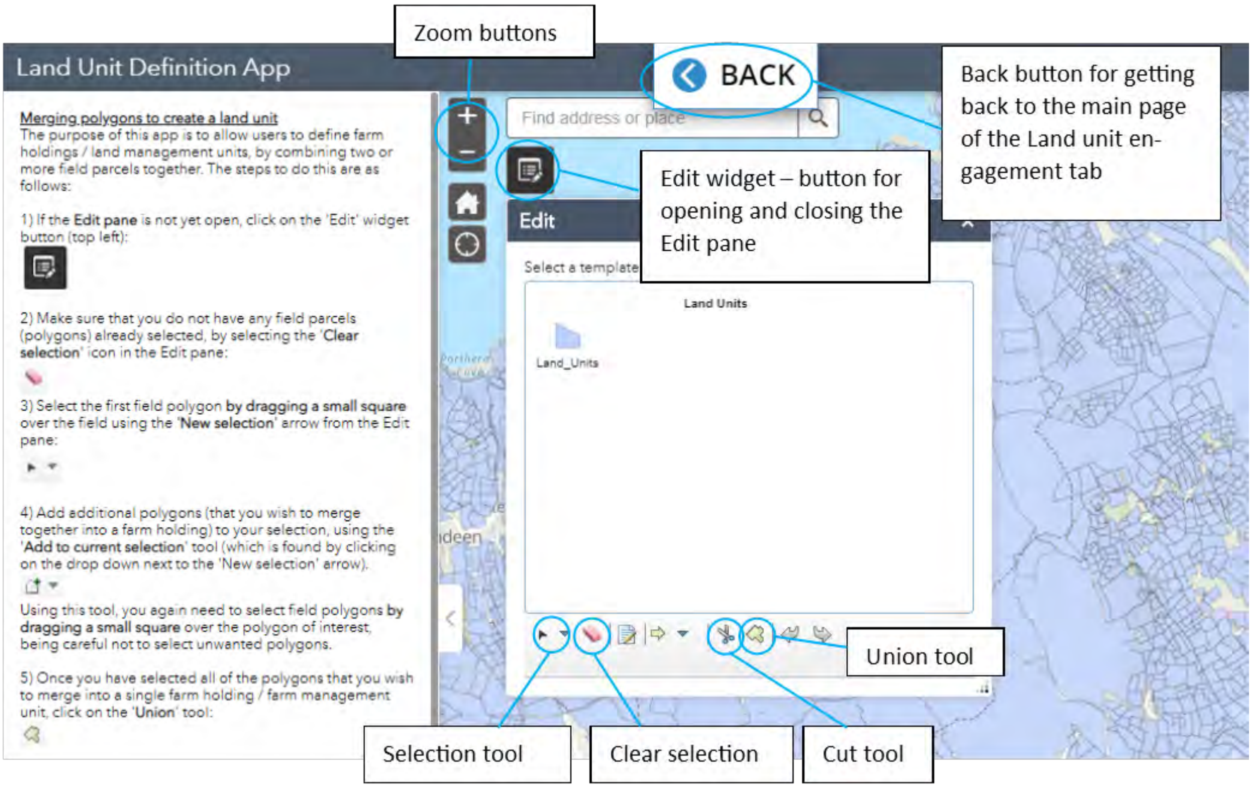
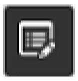


Figure 3. Land Unit Definition App.

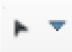
From within the Land Unit Definition App, the steps are as follows:

1. If the **Edit pane** is not yet open, click on the 'Edit' widget button (top left):



2. Make sure that you do not have any field parcels (polygons) already selected, by selecting the '**Clear selection**' icon in the Edit pane:

3. Select the first field polygon by dragging a small square over the field using the '**New selection**' arrow from the Edit pane:



4. Add additional polygons (that you wish to merge together into a farm holding) to your selection, using the '**Add to current selection**' tool (which is found by clicking on the drop down next to the 'New selection' arrow).

   Using this tool, you again need to select field polygons by dragging a small square over the polygon of interest, being careful not to select unwanted polygons.

5. Once you have selected all of the polygons that you wish to merge into a single farm holding / farm management unit, click on the '**Union**' tool:

If you zoom into an area in order to create a land unit and there is no polygon in the required location or the existing polygons do not meet your requirements, you have the following options:

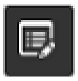
Edit polygons (in preparation for merging)

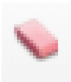
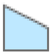
If there is a polygon in the required location but it is too large or the wrong shape, you can either:

- Use the cut tool  on the Edit pane to split the polygon in two (this is the equivalent of 'split' in ArcGIS desktop). You can also use this tool to cut a smaller polygon within an existing polygon - the two shapes created will be separate objects in the GIS layer.

- Delete the incorrect polygon and create a new one (see below).

Create new polygons (in preparation for merging)

1. If the Edit pane is not yet open, click on the 'Edit' widget button (top left):


2. Make sure that you do not have any field parcels (polygons) already selected, by selecting the 'Clear selection' icon in the Edit pane:

3. Select the Land Units template from the Edit pane:


4. Digitise (draw) your polygon in the required location.

Please only create a new polygon if there is a blank space where you need a polygon, do not create overlapping polygons. Once you have created a polygon, it can be merged/unioned with other polygons as required in order to create a land unit.

To move on to steps two or three, you will need to go back to the Land Unit Engagement App by clicking on the 'Back' button at the top of the land unit definition page (see Figure 3).

Actions that can be completed from the Land Unit Engagement App (continued):

2) Complete or update the land unit questionnaire or engagement details for a specific land unit. To do this, click on one of the polygons that make up the land unit of interest. A pop up will appear containing a link to a Survey123 form for entering or updating the information about this land unit (Figure 4).

(See Appendix for definitions of potentially ambiguous terms that are used in the survey form).

It is important that step 1 – merging of polygons to define a land unit – has been completed before completing the Survey123 Land Unit questionnaire and Engagement details form. This is because, when polygons are merged, the information (attributes) from only one of the polygons are kept – the polygon with the lowest OBJECTID (in a GIS layer, all objects (features) have a system-defined ID number called an OBJECTID). If you have completed the Survey123 form for a polygon or land unit and then merge it with another object with a lower OBJECTID, then the information you have already submitted via Survey123 will be lost.

3) View details or engagement information for a specific land unit.
To do this, simply click on one of the polygons in the land unit of interest. A pop up will appear (see Figure 4). Click on the ellipsis (...) and then 'View in Attribute Table'. In the Attribute Table, you can scroll to the right to view additional attribute fields. Alternatively, you can view these details within the Survey123 form (see point 2 above).

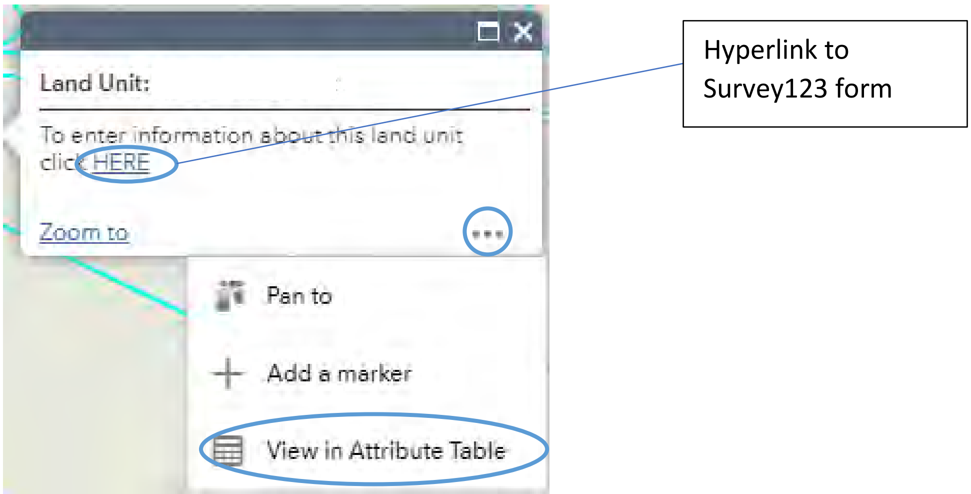


Figure 4. Land Unit Engagement tab – Land unit polygon 'Pop-up 'showing link to Survey123 form and link to Attribute table.

Interventions tab

Figure 5. Full screen view of the Interventions tab, showing the embedded Interventions Editing App.

Tab summary

The role of this tab is to allow users to view or input information about interventions undertaken as part of UST3. The content of this tab is an embedded web app, called the Interventions Editing App (see Figure 5 and Figure 6).

There are five types of intervention feature that you can interact with using this app:

1. Point Interventions
2. Line Interventions
3. Polygon Interventions
4. Land Unit (LU) Points
5. Field Parcel Interventions

From this app you can:

a. Digitise intervention features
b. Input information about features
c. View, edit or add to entered information

More details about this tab are provided below.

The five intervention types

An overview of the five intervention types:
(For more information on interventions and their relevant feature types see appendix)

1. **Point Interventions** - discrete interventions whose location can be represented using a single point and whose area or length does not need to be captured for the purpose of UST3 reporting. These include the following interventions:
    - Construct bridges/watercourse crossings for livestock
    - Construct livestock drinkers/feeders with hard bases
    - Gateway relocation from high risk area
    - Installation of: cross drains; livestock drinking troughs (in draining pens for freshly dipped sheep); piped culverts in ditches; secure holding areas to keep dipped sheep away from watercourses; sheep dip drainage aprons and sumps; water gates
    - In-stream NFM measures
    - Provision of alternative drinking water for livestock - e.g. troughs. Includes associated pipework and pumps.
    - Relocation of sheep dips to lower risk locations
    - Resurfacing of gateways
    - Other (for point interventions/features not listed above)
2. **Line Interventions** - linear interventions whose length needs to be captured for the purpose of UST3 reporting. These include the following interventions:
    - Ditch management
    - Establish: in-field grass buffer strips; new hedges; riparian buffer strips
    - Hedgerow management
    - Install: non-watercourse fencing; watercourse fencing
    - Management of livestock and machinery hardcore tracks
    - Stone wall restoration
    - Other (for linear interventions not listed above)
3. **Polygon Interventions** - areal interventions whose location and size are best represented by a polygon feature and whose area needs to be captured for the purpose of UST3 reporting. Examples include:
    - Creation of wet/water holding features
    - Management of in-field wet /water holding features
    - Management of moorland - rewetting (e.g. Grip blocking drainage channels)
    - New roofing (e.g. for slurry and silage stores)

   - Yard works and rainwater goods
   - Earth banks and soil bunds
4. **Land Unit (LU) Point** - a single point for capturing multiple advice measures given to a land manager/land unit. This is for capturing advice that is farm-wide (i.e. might be relevant to multiple farm-fields), rather than associated with a specific point location. Examples include:
   - Adoption of a nutrient management plan
   - Reduce fertiliser application rates
   - Leave residual levels of non-aggressive weeds in crops
5. **Field Parcel Interventions** - interventions that take place on specific farm-fields. For the recording of this type of intervention, this app has been pre-populated with a GIS layer of farm-fields. This layer is only visible when zoomed in on an area. Field parcel interventions include the following measures:
   - Arable reversion to grassland with low fertiliser input
   - Create or maintain uncropped cultivated margins
   - Cultivate land for crops in spring rather than autumn
   - Enhanced management of maize crops
   - Establish cover crops in the autumn
   - Establishment of two year sown legume fallow
   - Management of: invasive non-native species (INNS); permanent grassland with very low inputs; rough grazing for birds
   - Nil fertiliser inputs
   - Reducing stocking density and fertiliser inputs on intensive grassland adjacent to a watercourse
   - Soil aeration
   - Undersown spring cereals

Each intervention type has its own GIS feature layer.

Tab instructions

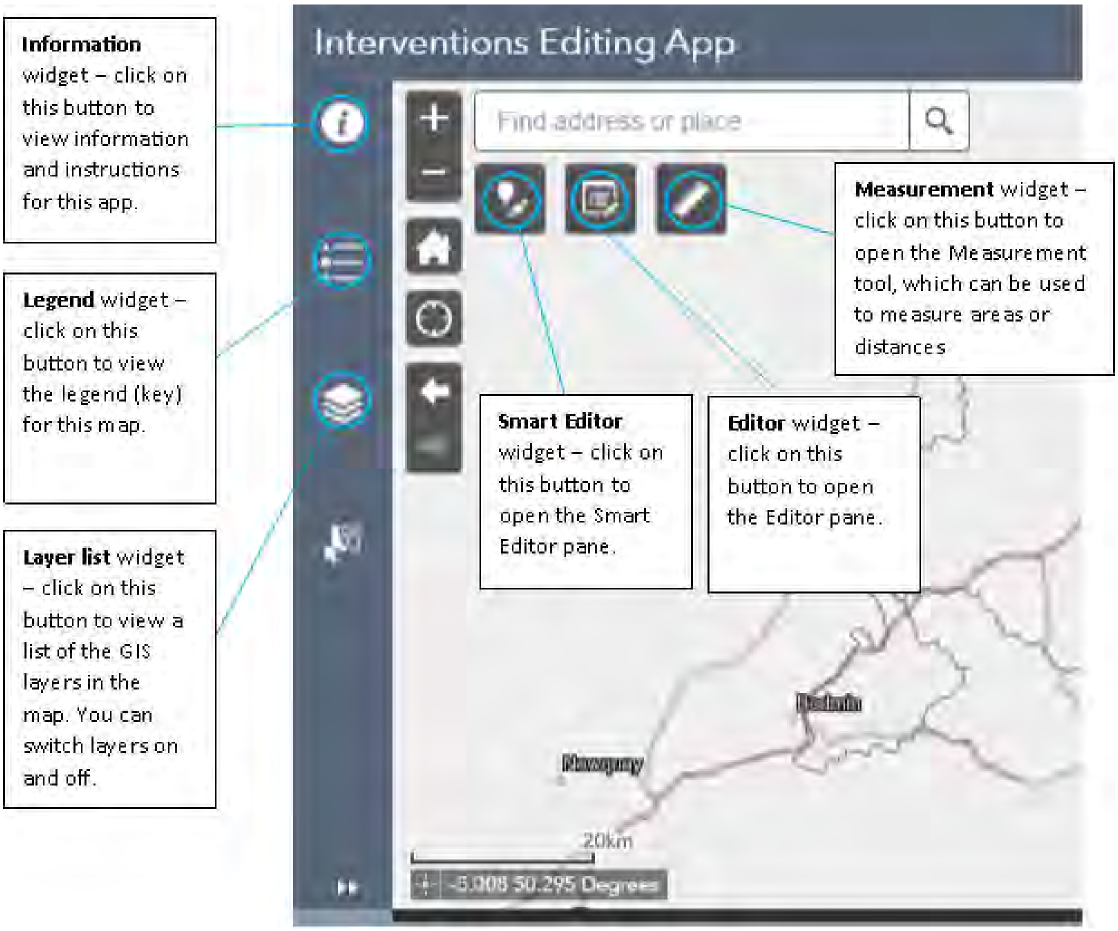


Figure 6. Interventions Editing App.

Step-by-step guide:

From the Interventions Editing App, you can:

a) Digitise intervention features

To digitise an intervention, find or zoom into the location where you want to add a point, line or polygon. Then select the **Smart Editor** widget in the top left hand corner of the map (see Figure 6). From the Smart Editor pane that opens up, select the relevant template (e.g. 'Point interventions') and then insert or draw a feature in the required location (Figure 7).

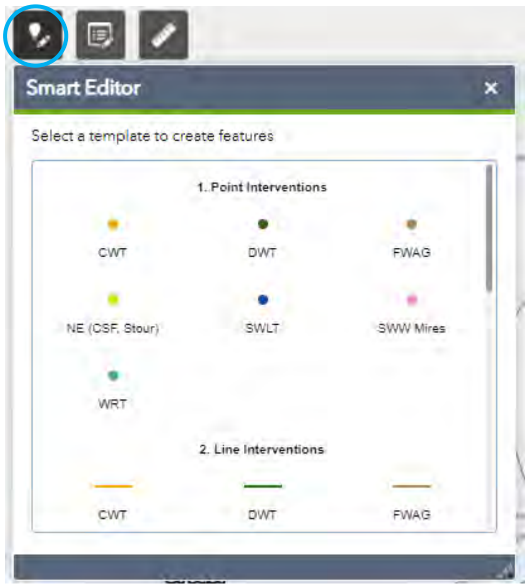


Figure 7. Smart Editor widget showing Intervention templates - 1. Point Interventions, 2. Line Interventions, etc

In the case of Field Parcel interventions the app has been pre-populated with a GIS layer of farm-fields so in most cases you should not need to digitise a polygon. However, if there is no polygon in the required location open the Edit widget (next to the Smart Editor on the top left hand corner) and click on the 'Field parcel interventions' template within the Edit pane that opens up (Figure 8).

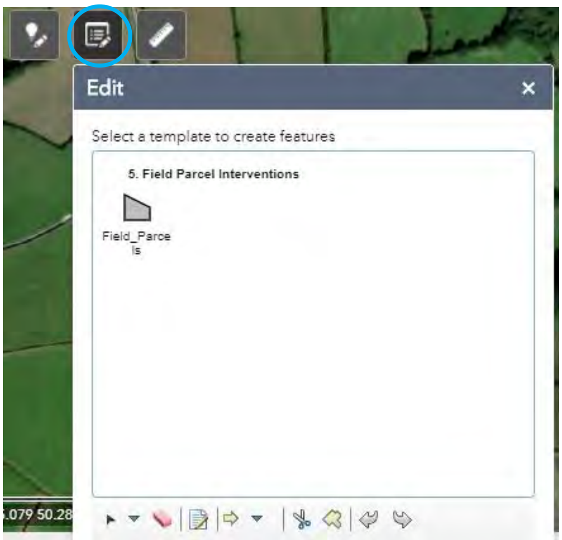


Figure 8. Editor widget from where you can select the Field Parcel template

You can then digitise a new polygon in the required location. If necessary you can also split/cut  Field Parcel polygons using the cut tool in the Edit pane.

Once you have digitised a feature, you need to click **'Save'** in the Smart Editor/Edit pane for your feature to be recorded.

If you have started to create a feature by digitising it but are not happy with it and wish to delete it, click on **'Cancel'** in the Smart Editor pane.

In the case of LU Points, it might be useful to add the point in a key/memorable location, such as the main farm building, or a main car park, as long as this falls within the defined boundaries of the land unit of interest. This might help you to re-locate the point if edits are required.

Furthermore, if you have given advice on separate dates and you want to record this, you will need to digitise/add a separate LU Point for advice given on each separate date. Similarly, if pieces of advice given on the same day have different end dates and you want to record this, you will need to do separate LU Point(s) in order to be able to account for the different end dates in the information you input through Survey123.

Field Parcel Interventions should not generally require digitisation as this app has been pre-populated with a GIS layer of farm-fields.

To aid accurate digitisation of line and polygon features, you can use the Measurement tool (Figure 9) to first draw a line or polygon of the required length or area, respectively, in the correct location. Then, without clearing the newly drawn measurement feature, click on the Smart Editor widget, select the required template and then digitise a line intervention or polygon intervention on top of the measurement feature. Once your intervention has been digitised, you can click on the Measurement widget and then 'Clear' to remove the measurement feature.

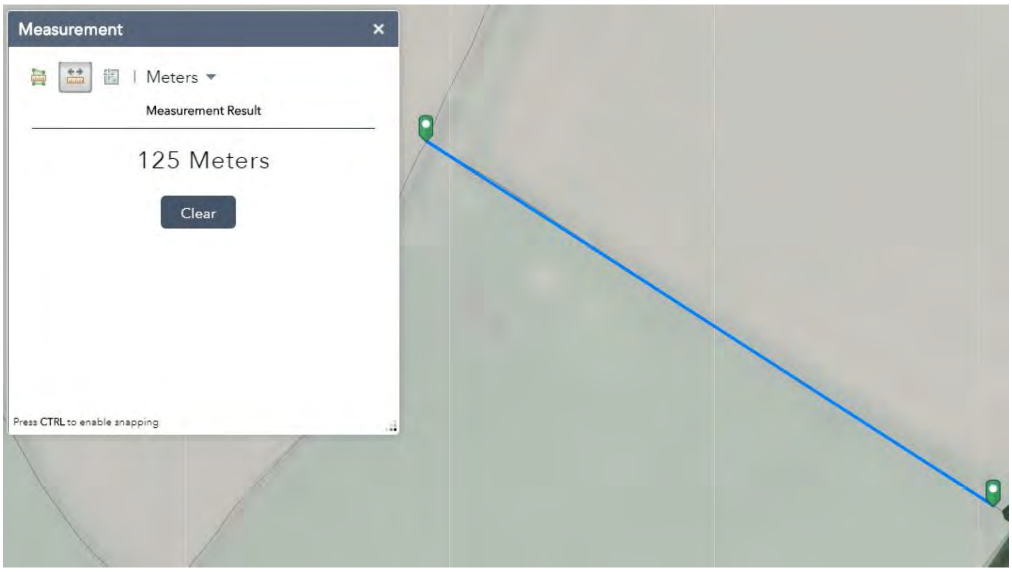


Figure 9. Example of using the line measurement tool to draw a temporary line measuring 125 m.

b) Input information about features

To enter information (e.g. Partner, type of intervention) about a **Point** or **Line Intervention**, keep the Smart Editor pane *open* and then select the feature of interest. You will then be able to enter information about the intervention feature into the Smart Editor pane (Figure 10). If you have just digitised a Point or Line Intervention, this pane will already be open for the feature digitised.

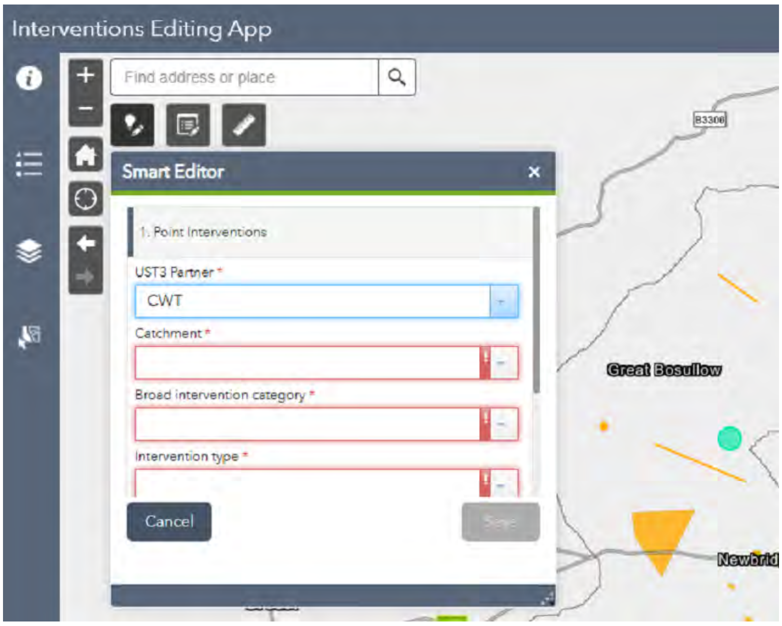


Figure 10. Smart Editor pane open for data entry about a point intervention.

To enter information (e.g. Partner, advice given) about a **Polygon**, **LU point**, or **Field Parcel**, *close* the Smart Editor pane and then select the feature of interest. A pop-up will appear, from which you can click on a hyperlink to a Survey123 form (Figure 11). The survey123 will open in a new browser.

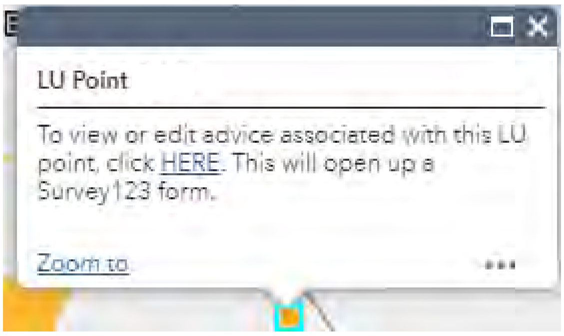


Figure 11. Land unit intervention - pop-up containing link to survey123 form for data entry.

All interventions recorded though the Smart Editor or Survey123 form will require a 'Start date' to be provided and where relevant an end date.

For point, lines and polygons – more physically 'built' interventions, please provide the date at which they were constructed or implemented.

Land unit points – please provide the date of implementation or behaviour change. One LU point can have multiple items selected and if these multiple items/advice were given and implemented all at the same time, they can have a single start date (and if relevant a single end date). If that isn't appropriate you will need to add a new point for every individual item and give each a single start and end date.

For Field Parcel interventions, again please provide the date of implementation or behaviour change. For each option that is selected from the multiple choice list, a 'Start date' and 'End date’ question will become available (below the list). This means that every intervention that is being applied to this field parcel will be captured and a start and end date given for each item.

Some interventions may occur only once or at one specific time e.g. soil aeration so an end date will not be relevant.

Tip: If you have selected an intervention feature and there are several close to the point that you clicked, you can use the arrow button on the top right of the pop-up to scroll through the pop-up of the other nearby features.

c) View, edit or add to entered information.

To **view** entered information about a Point or Line Intervention, simply select the feature of interest and a pop-up will appear. The Smart Editor pane can be open or closed when you do this but if a template (e.g. 1. Point Intervention) is already selected within the Smart Editor pane you will need to 'de-select' it first by clicking on the selected symbol in the Smart Editor pane. To **edit** the information however, the Smart Editor pane must be open.

To **view** entered information about a Polygon or Field Parcel from within this app, ensure that the Smart Editor pane is *open* and then select the feature of interest. As above, if a template (e.g. 3. Polygon Intervention) is already selected within the Smart Editor pane you will need to 'de-select' it first by clicking on the selected symbol in the Smart Editor pane.
To **edit** Polygon or Field Parcel information, ensure that the Smart Editor pane is *closed* and then select the feature of interest. A pop-up will appear, from which you can click on a hyperlink to a Survey123 form.

To **view** or **edit** entered information about an LU Point, ensure that the Edit pane is *closed* and then select the feature of interest. A pop-up will appear, from which you can click on a hyperlink to a Survey123 form.

You can view the intervention layers' attribute tables by clicking on the arrow tab at the bottom of the page. 

Tips for this tab:

The 'Field Parcel Interventions' layer is only visible when zoomed in to a local, 'neighbourhood' scale.

You can toggle layers off and on using the Layers widget  . It might sometimes be useful to turn the Field Parcel Interventions layer off in order to see the satellite imagery underneath.

You can view the intervention layers' attribute tables by clicking on the arrow tab at the bottom of the page .

See Table 1 for a Summary of data input and viewing options according to intervention feature type. See Table 2 for a summary of intervention driver requirements by feature type. See Appendices 3 and 4 for information on intervention drivers and a list of interventions by feature type.

Table 1. Summary of data input and viewing options according to intervention feature type.

<table>
<tr><th>Intervention type / Layer name</th><th>Feature digitisation required?</th><th>How to input details about a specific intervention of this type</th><th>Options for viewing entered information. The option necessary for editing information is highlighted in bold.</th></tr>
<tr><td>Point Interventions</td><td>Yes – point required to represent location of the intervention.</td><td rowspan="2">Using the Smart Editor. With the Smart Editor pane open, select the feature of interest. An editable pop-up will appear.</td><td rowspan="2">Smart Editor Pane (click on feature whilst Smart Editor open).

Map pop-up (click on feature whilst Smart Editor closed).

Attribute table. Two options:
1) Whilst Smart Editor closed, click on feature of interest, click on ellipsis (…), ‘View in Attribute Table’.
2) Click on arrow tab at the bottom of the page to view attribute tables.
</td></tr>
<tr><td>Line Interventions</td><td>Yes – a line needs to be digitised. Length of the digitised line is important for reporting.</td></tr>
<tr><td>Polygon Interventions</td><td>Yes – a polygon needs to be digitised. Area of the polygon is important for reporting.</td><td rowspan="3">Via Survey123 form. With the Smart Editor pane closed, select the feature of interest. A pop-up will appear, from which you can click on a hyperlink to a Survey123 form.</td><td rowspan="3">Re-open the Survey123 form. With the Smart Editor pane closed, select the feature of interest and on the pop-up, click on the hyperlink to the Survey123 form.

Attribute table. Two options:
1) Whilst Smart Editor closed, click on feature of interest, click on ellipsis (…), ‘View in Attribute Table’.
2) Click on arrow tab at the bottom of the page to view attribute tables.
</td></tr>
<tr><td>LU Points</td><td>Yes – but only one LU Point per land unit. A single LU Point can be associated with multiple advice measures.</td></tr>
<tr><td>Field Parcel Interventions</td><td>In most cases – no.

Field Parcel Interventions should not require digitisation as this app has been pre-populated with a GIS layer of farm-fields. If, however, a field parcel is not already present in the required location, a field polygon can be digitised.</td></tr>
</table>

Table 2. Summary of intervention driver requirements by feature type.

Intervention type / Layer name	Intervention driver requirement information
Point Interventions	No drivers required - point interventions aren't assigned drivers
Line Interventions	Up to three drivers can be assigned. At least one driver must be assigned. The intervention drivers do not influence which monthly reporting item(s) an intervention feeds into. However, relevant drivers should still be set, to aid additional categorisation, analysis and reporting of interventions.
Polygon Interventions	Up to three drivers can be assigned. At least one driver must be assigned. Some drivers cause an intervention to feed into a particular monthly reporting item (e.g. 'Area of new habitat') – see appendices 3 and 4.
LU Points	No drivers required - LU point interventions aren't assigned drivers
Field Parcel Interventions	Multiple drivers can be assigned. Some drivers cause the field parcel area to feed into a particular monthly reporting item – see appendices 3 and 4.

Field Activation tab

⚠ Completion of this tab is important as the areas turned 'Active' contribute to the cumulative total of **Total area of farms/land units under 'Active management'** for the reporting of the UST3 ODI to SWW.

All areas turned active feed into the reporting so you must ensure that the correct areas are selected. Please also ensure that the date land became active is filled in with the appropriate date.

What constitutes 'Active'?

If there have been new actions/measures on a farm/land unit/field parcel since April 2020. This includes new:

- advice that is being implemented across the whole farm/land unit and/or behaviour changes (i.e. items that are recorded through the Land Unit point intervention feature),
- physical interventions that are recorded using points, lines and/or polygon intervention features, or
- measures reported through the Field-parcel intervention feature.

There must be a minimum of one of the above interventions recorded within the farm/land unit/field parcel before it can to be classed as 'Active'. For a whole land unit (i.e. a farm) to be classed as active, there should an expectation of changes in behaviour/management across the majority of the land unit (i.e. farm).

The interventions must also relate to new engagement since April 2020 or follow-on agreements to replace or update AMP6 work.

If you are recording only a maintenance visit or your visit has been to check on pre-AMP7 works that are continuing but not new, you cannot record these areas as Active or count them towards AMP7 reporting.

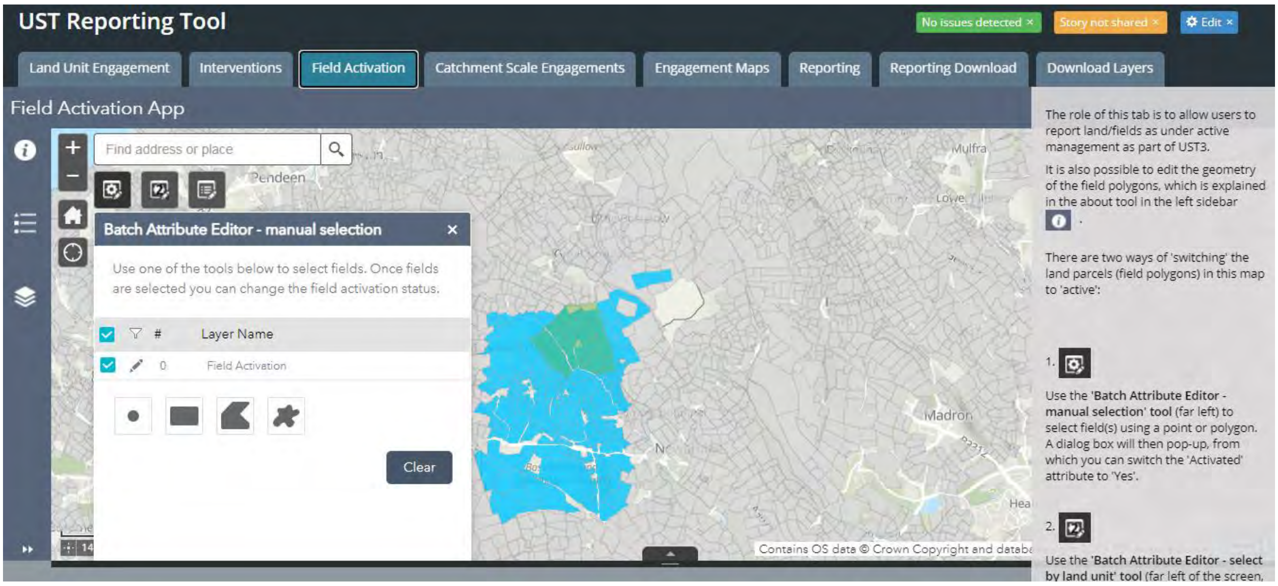


Figure 12. Full screen view of Field Activation tab showing Field Activation App.

Tab summary

The role of this tab is to allow users to report land/fields as being under active management as part of UST3. The content of this tab is an embedded web app, called the Field Activation App (Figure 12).

The map in this tab contains a GIS polygon feature layer called 'Field activation'. This layer contains field polygons derived from a number of potential sources, depending on the area of interest /delivery partner. Registering a land area / field parcel as 'active' is achieved by switching an attribute called 'Activated' to 'Yes'.

Tab instructions

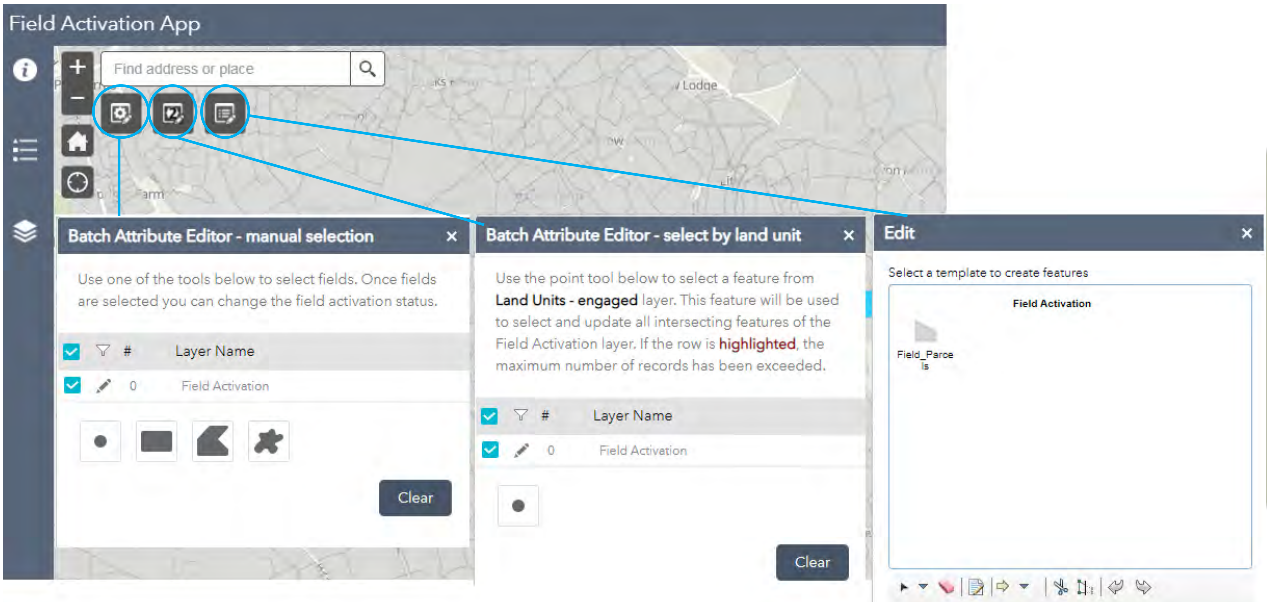
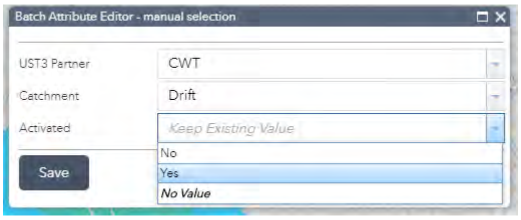


Figure 13. Field Activation App and associated widgets [NB. All widgets open at the same time for illustration only. In the portal only one widget (e.g. Edit) can be open at a time].

There are two ways of 'switching' the land parcels (field polygons) in this map to 'active':

1. Use the 'Batch Attribute Editor - manual selection' tool (far left) to select field(s) using a point or polygon. A dialog box will then pop-up, from which you can switch the 'Activated' attribute to 'Yes'.



2. Use the 'Batch Attribute Editor - select by land unit' tool (top left of the screen, to the right of the manual selection tool). Use a point to click on and select a land unit (note - only engaged land units are shown). All the fields that intersect (correspond to) this land unit will then be selected automatically. A dialog box will then pop-up, from which you can switch the 'Activated' attribute to 'Yes'.

⚠ Before editing the dialog box, ensure that only the correct fields have been selected. If more fields than required are highlighted, then you will need to either: a) use the manual selection method instead or b) turn all the selected/highlighted fields active and then use the manual selection method to switch the required fields back to inactive.

Tip - you can turn the 'Land units - engaged' layer off using the Layers widget.

Catchment Scale Engagements tab

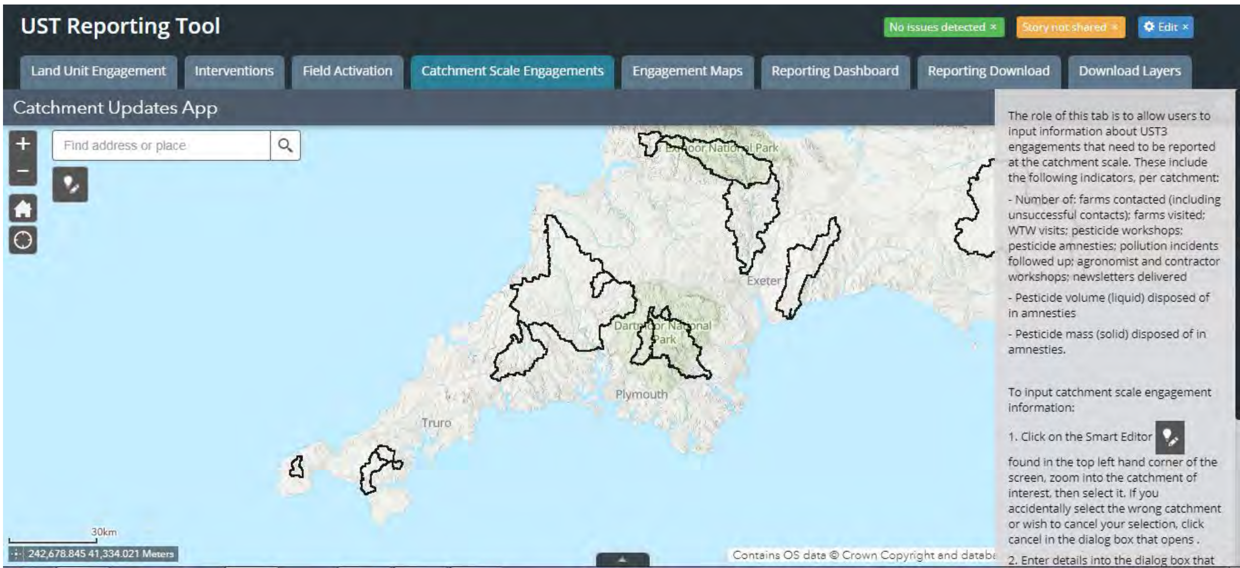


Figure 14. Full screen view of Catchment Scale Engagement tab showing Catchment Updates App.

Tab Summary

The role of this tab is to allow users to input information about UST3 engagements that need to be reported at the catchment scale. These include the following indicators, per catchment:

- Number of:
    - farms contacted (including unsuccessful contacts – those that do not lead to active management under UST3);
    - farms visited (including– those that do not undertake interventions or changes in management under UST3);
    - WTW visits;
    - pesticide workshops;
    - pesticide amnesties;
    - pollution incidents followed up;
    - agronomist and contractor workshops;
    - newsletters delivered
    - Volunteer/community events
- Pesticide volume (liquid) disposed of in amnesties
- Pesticide mass (solid) disposed of in amnesties

The content of this tab is an embedded web app, called the ‘Catchment Updates App’ (Figure 15).

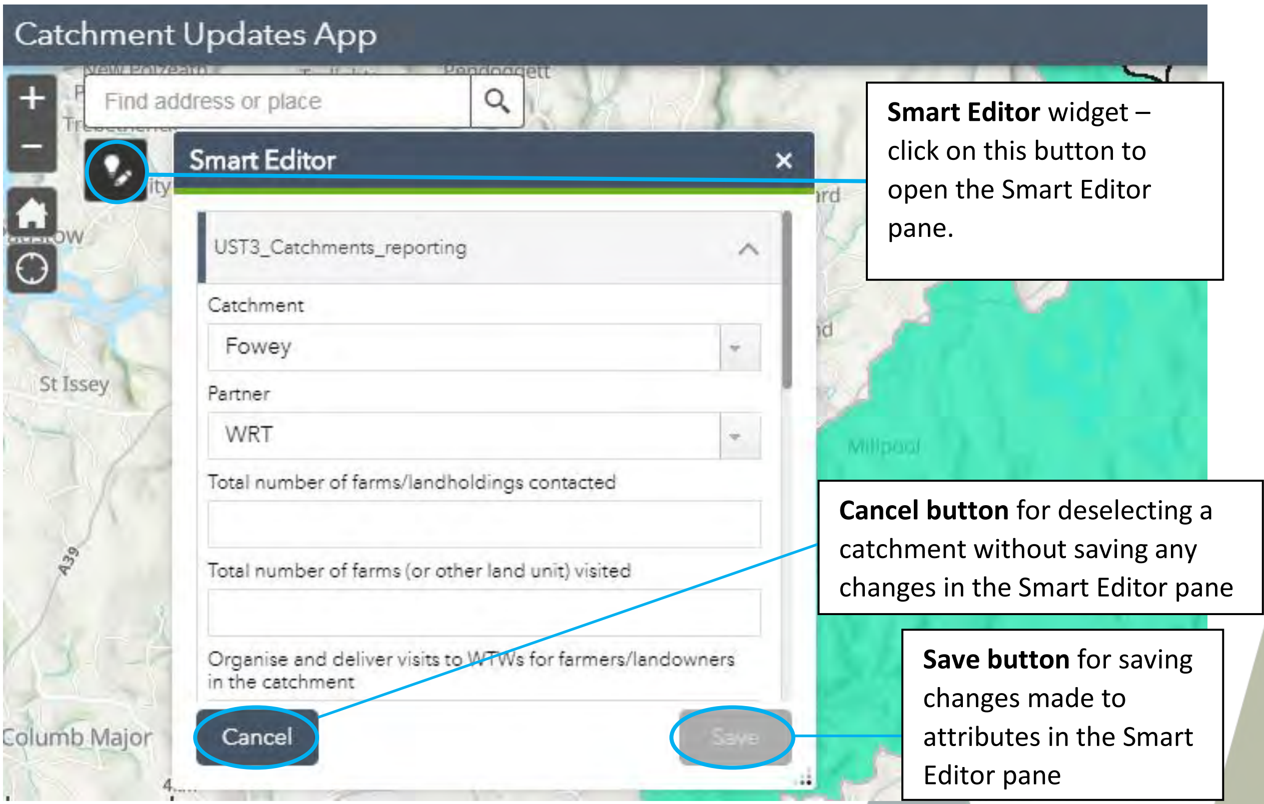


Figure 15. Catchment Updates App with Smart Editor pane open and an example catchment (Fowey) selected.

Tab instructions

To input catchment scale engagement information:

1. Click on the Smart Editor widget found in the top left hand corner of the screen, zoom into the catchment of interest, then click within the black polygon outline to select the desired catchment. If you accidentally select the wrong catchment or wish to cancel your selection, click cancel in the dialog box that opens (see Figure 15).

2. Enter details into the dialog box that opens in the Smart Editor pane, then click Save (see Figure 15).

To **view catchment-scale engagement information**, you can either click on the catchment of interest, or view the catchment layers' attribute table by clicking on the arrow tab at the bottom of the page. 

Engagement Maps tab

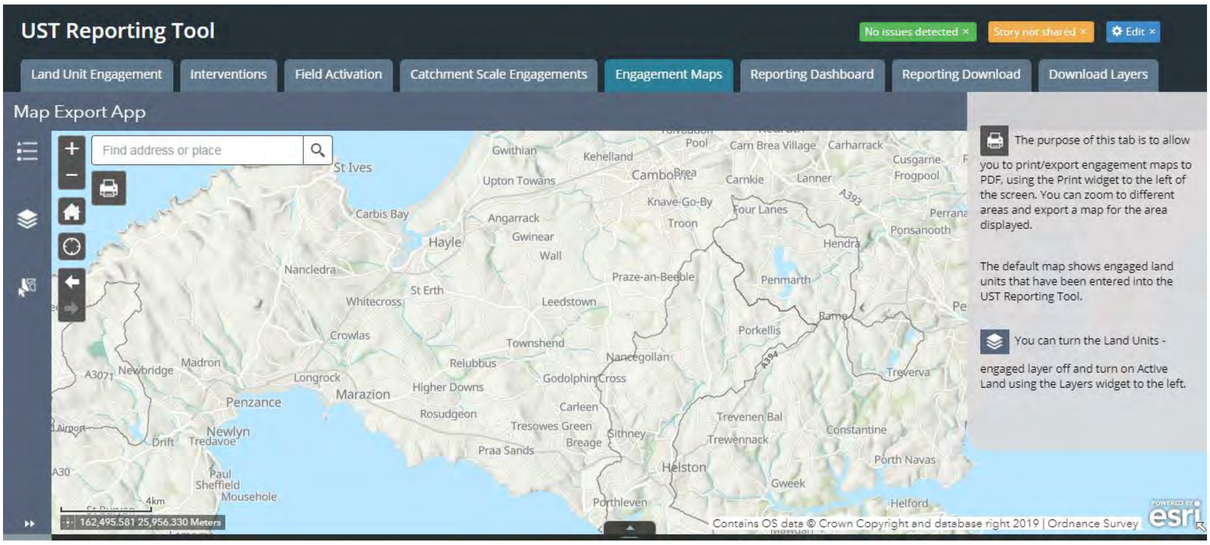


Figure 16. Engagement Maps tab showing Map Export App.

The purpose of this tab is to allow you to print/export engagement maps to PDF, using the Print widget to the left of the screen. In the pop-up window you can set the Title and format then click Print. A link to the new map PDF is then added to the pop-up (see Figure 17). Click on Map PDF for it to open in a new window from where you can download and save.

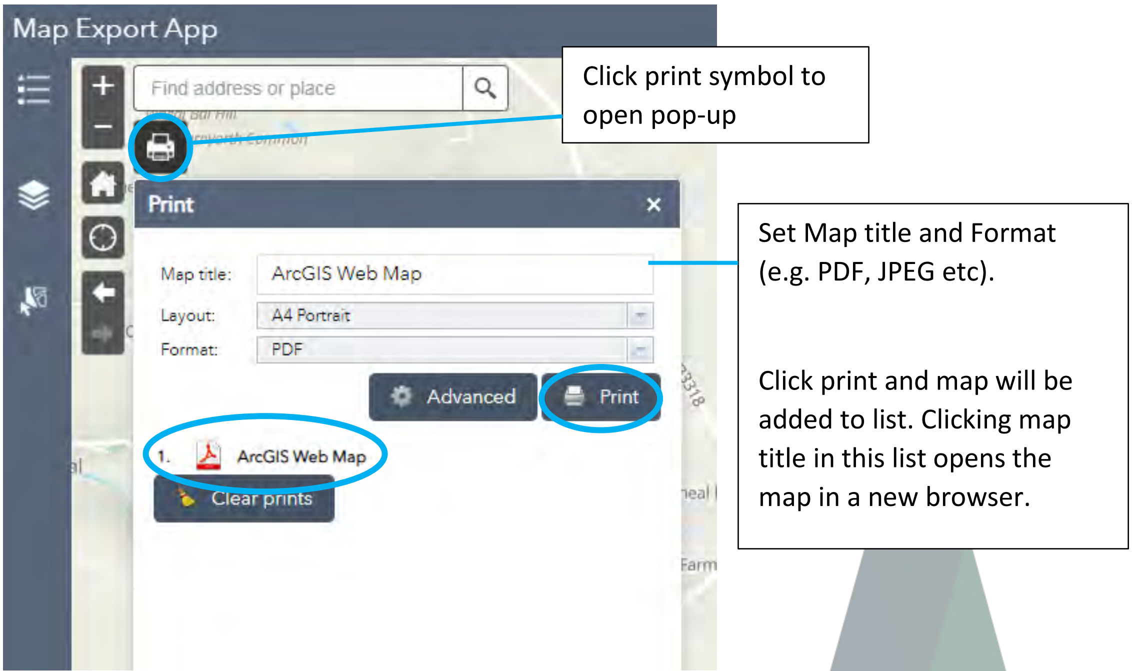


Figure 17. Engagement Map tab pop-up

The default map shows engaged land units that have been entered into the UST Reporting Portal. You can zoom to different areas and export a map for the area displayed.

Tip: You can turn the Land Units - engaged layer off and turn on Active Land using the Layers widget to the left.

Reporting Dashboard tab

Figure 18. UST Reporting Dashboard (with dummy data)

The reporting Dashboard provides a visual summary of key performance indicators.

Each of the key reporting features in this dashboard will contain a live count (e.g. Number of Farms Contacted, Trees planted) or a cumulative total (e.g. Area of new habitat created) of areas intervened on for your catchment.

Use the drop down on the left of the window to select the catchment of interest or move around the map to filter the results (Figure 18).

This tab is just for visualisation and reviewing summary data. See information on the next tab for reporting and extracting data.

Reporting Download tab

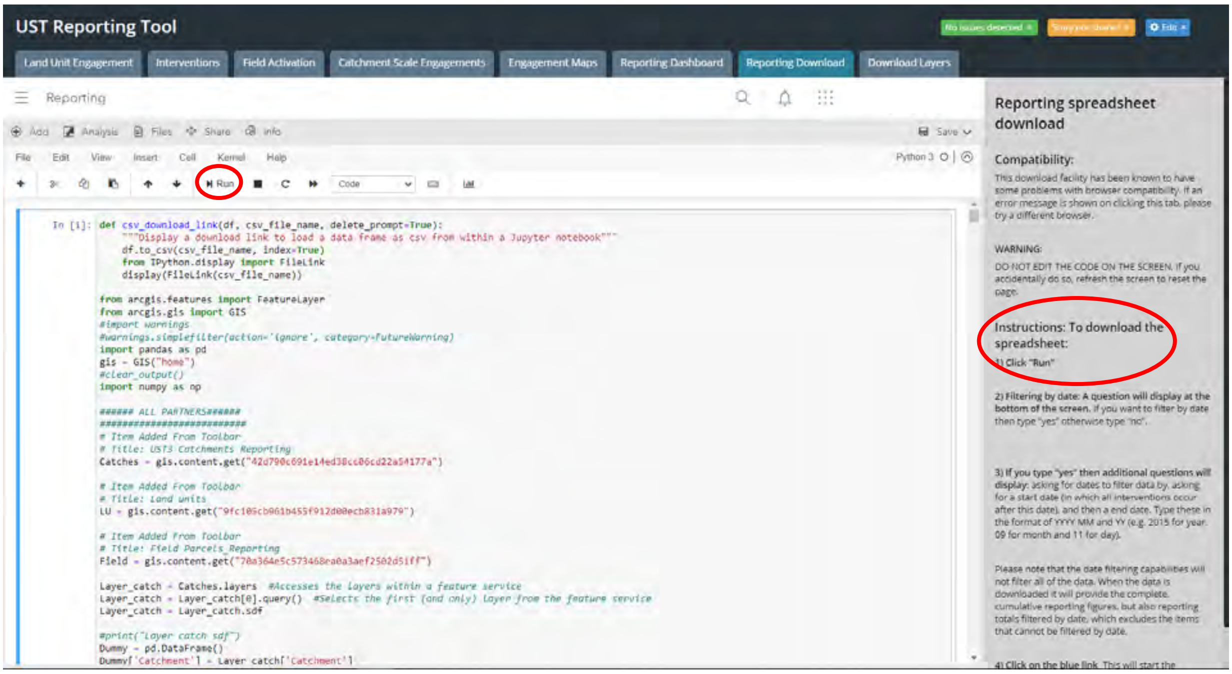


Figure 19. Full screen view of Reporting Download tab

This tab is for downloading the reporting spreadsheet with all the required data for UST reporting, in the correct format. The tab contains a ‘notebook’ containing script which pulls together all the information inputted so far into relevant reporting items to populate a spreadsheet. **It is also possible to filter (relevant data) by date.**

It may look intimidating but there is only one button you need to press. See below for step by step instructions.

WARNING:

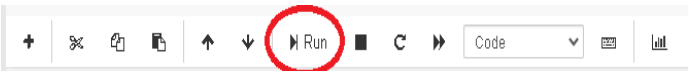
DO NOT EDIT THE CODE ON THE SCREEN, if you accidentally do so, refresh the screen to reset the page, and do not save changes.

Compatibility:

This download facility has been known to have some problems with browser compatibility. If an error message is shown when you click this tab, please try a different browser. There is no internet browser in particular that works more often than others, so please try any other internet browser you have available, and if that doesn’t work, try another. Usually, this works first try though.

Instructions: To download the spreadsheet:

1) Click "Run" located in the tool bar across the top of the reporting window.



2) The following question will display at the bottom of the screen. If you want to filter by date then type "yes" otherwise type "no".

```
Do you want to filter results by date? Does not filter anything in the catchment reporting polygon (see manual). (Yes/No):
```

3) If you type "yes" then additional questions will display: asking for dates to filter the data by.

- Start of reporting period: Enter the start date 'year' (YYYY) - this is the year in which all the interventions you want to report occur after this date. E.g. 2017.
- Enter a month (MM). E.g. 04 (for April)
- Enter a day (DD). E.g. 01
- Then enter the end date of the reporting period you are interested in.
  In the same format of YYYY MM and DD (e.g. 2019 for year, 03 for month and 31 for day).

```
Start of reporting period. First enter a year(YYYY): 2011
Enter a month (MM): 11
Enter a day(DD): 01
End of reporting period. First enter a year(YYYY): 2020
Enter a month (MM): 11

Enter a day(DD): 01
```

Please note that the date filtering capabilities will not filter all of the data as not all input data collects date information.

4) Click on the blue link This will start the download after a few seconds. Clicking the link may open a new window/tab.

Reporting_spreadsheet.csv

Click "Reporting_spreadsheet.csv" link above

When the data is downloaded the spreadsheet produced will provide the complete, cumulative reporting figures, but also reporting totals filtered by date (excluding the items that cannot be filtered by date).

All reporting items (cumulative totals)

		Drift	Upper Cob	College ar	Stithians	Lower Cober
1						
2	All reporting items (cumulative totals for UST)					
3	Total area of farms/landholdings in catchment (Ha)	0	0	0	0	0
4	Total number of farms/landholdings contacted	0	0	0	0	0
5	Total number of farms (or other land unit) visited	0	0	0	0	0
6	Total number of farms/land units receiving advice from UST farm advisors	0	0	0	0	0
7	Total number of farms/land units under 'Active Management'	0	0	0	0	0
8	Total area of farms/land units under 'Active management (Ha)'	0	0	0	0	0
9	Linear riparian measures contributing to river improvement/protection (km)	0	0	0	0	0
10	Riparian buffers created (km)	0	0	0	0	0

Subset of reporting items filtered by date.

Reporting items that are filtered by date	0	0	0	0	0
Total number of farms/land units receiving advice from UST farm advisors	0	0	0	0	0
Total number of farms/land units under 'Active Management'	0	0	0	0	0
Total area of farms/land units under 'Active management (Ha)'	0	0	0	0	0
Linear riparian measures contributing to river improvement/protection (km)	0	0	0	0	0
Riparian buffers created (km)	0	0	0	0	0
Riparian hedgerows (km)	0	0	0	0	0
Riverside Fencing (km)	0	0	0	0	0
Ditch management (km)	0	0	0	0	0
In-field grass buffer strips (km)	0	0	0	0	0
Areal Biodiversity (Ha)	0	0	0	0	0
Area of new habitat (Ha)	0	0	0	0	0

<u>Download layers tab</u>

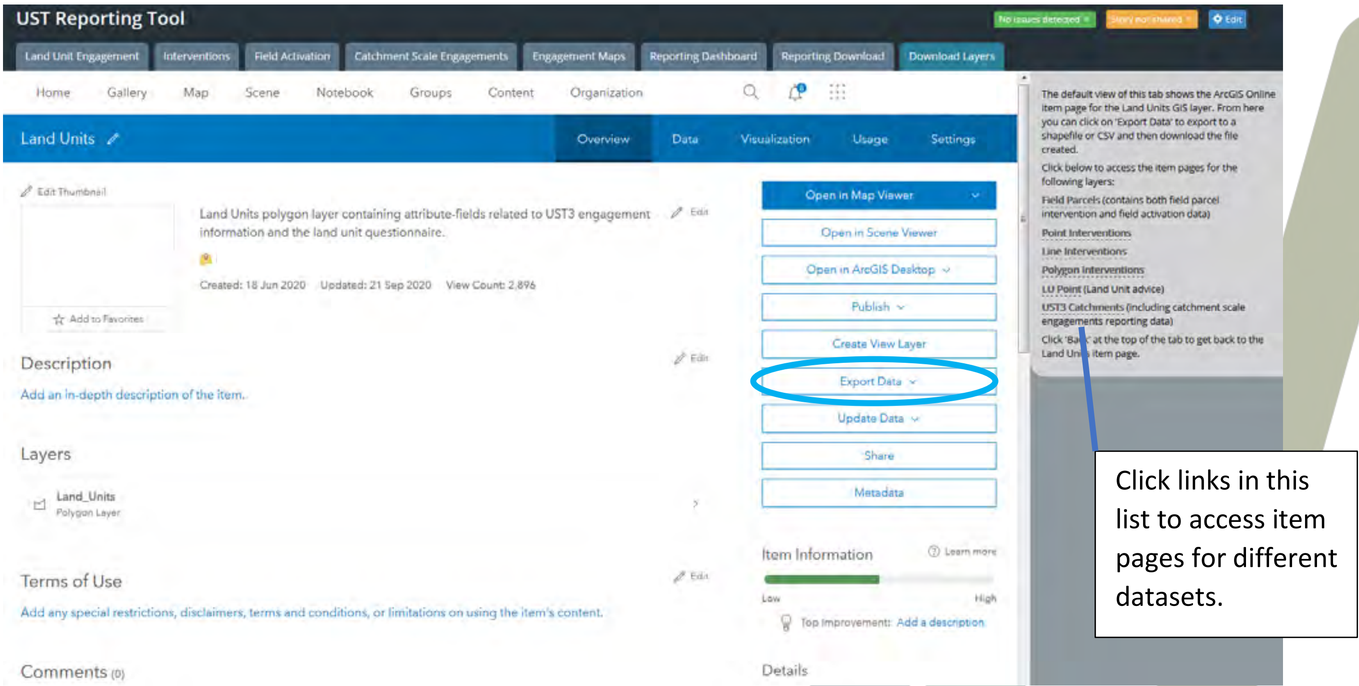


Figure 20. Full screen view of the Download Layers tab

The purpose of this tab is to provide you with options for exporting or downloading the data that you have entered through the various Apps as shapefiles, for use in your own GIS projects or as CSV files.

The default view of this tab shows the ArcGIS Online item page for the Land Units GIS layer. From here you can click on 'Export Data' (in the list on the right hand side) to export to a shapefile or CSV and then download the file created (see Figure 20).

In the grey box on the right hands side of this screen you have options to click hyperlinks which will take you to other item pages (see Figure 20).

Here you can access the item pages for the following layers:

- Field Parcels (contains both field parcel intervention and field activation data)
- Point Interventions
- Line Interventions
- Polygon Interventions
- LU Point (Land Unit advice)
- UST3 Catchments (including catchment scale engagements reporting data)

If you navigate away from the Land Units download page you will have an option to click a 'Back' button, at the top of the tab to return to it.

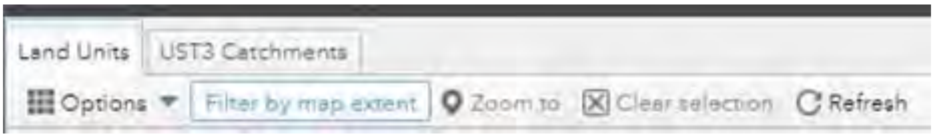
Hints and Tips

How to apply a temporary filter to a layer

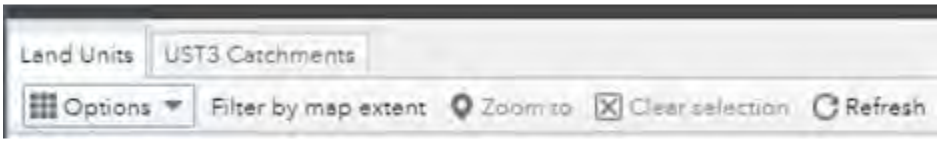
In the UST Reporting Portal, you can filter a layer by its attributes, so that only some of the objects (point, lines or polygons) are displayed, and only these records are shown in the attribute table. For example, on the Land Unit Engagement tab – Land Unit Engagement App, you could filter the Land Units layer to only show land units where the UST3 Partner is set to your organisation.

To do this, you would need to:

1. Open up the Land Units attribute table (by click on the arrow  at the bottom of the page). Then click on the Land Units attribute table tab (if it isn't already selected):



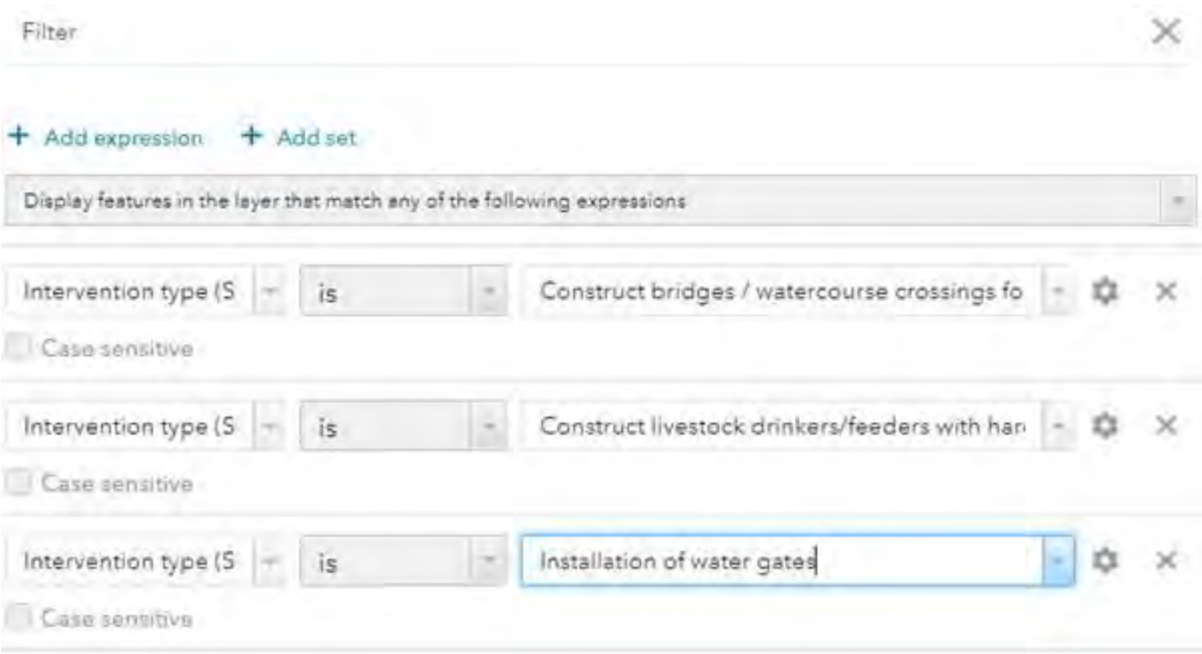
2. If you want to see all records in the layer and apply the filter to the whole layer, not just the part of the layer currently visible in the map, then turn off 'Filter by map extent':



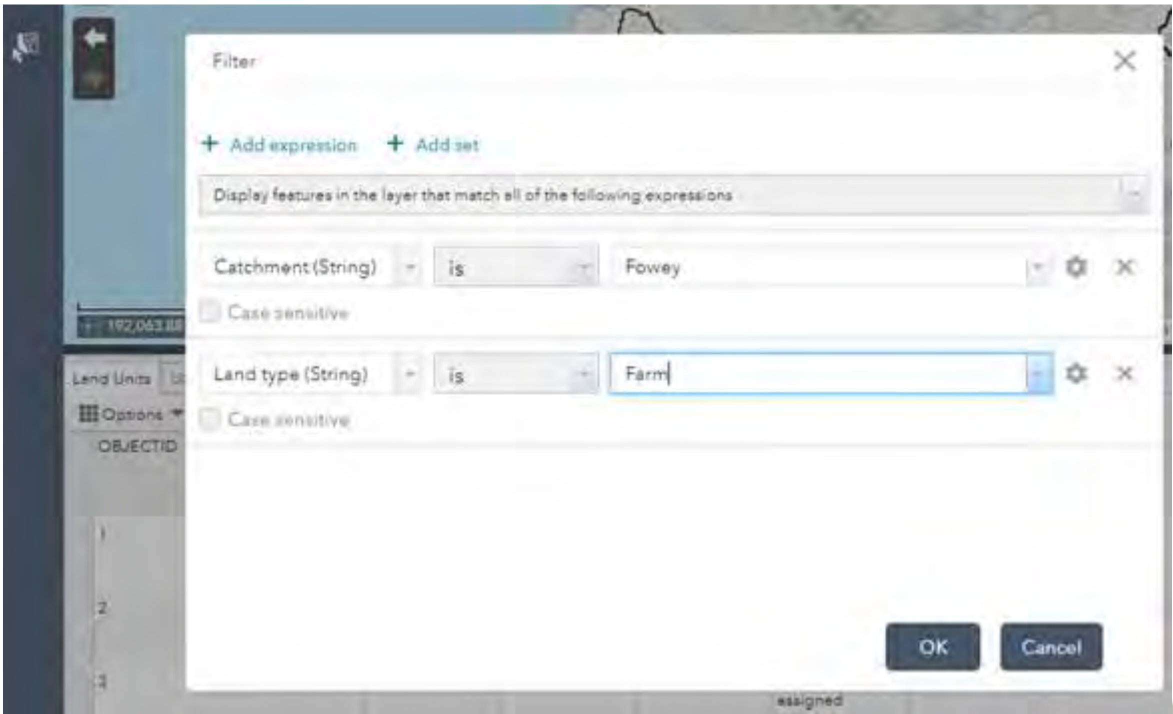
3. Then click on 'Options' (far left, see above screenshot) and then 'Filter'. You can then set a filter expression such as UST3 Partner is [Your organisation name]:

Once the filter has been applied, you will only see the applicable land units. You can remove the filter again when you want to see all land units by deleting the expression (clicking on the cross on the far right in the above screenshot).

You can apply more than one expression to filter by. For example, on the 'Intervention' tab, you could apply a filter to the point interventions layer to only see selected intervention types:



Note that for the above to work correctly, the top option must be set to 'Display features in the layer that match **any** of the following expressions'. It is also possible to have expressions where you want to 'Display features in the layer that match **all** of the following expressions'. For example, you may want to apply a filter to display only land units that are farms in a specified catchment:



Appendix

Appendix 1: Glossary of common GIS terms:

Attribute Table:
A database or tabular file containing information about a set of geographic features, usually arranged so that each row represents a feature and each column represents one feature attribute.

Digitizing:

This is the process of creating new data (points, lines or polygons) or converting geographic data either from a hardcopy or a scanned image into vector data by drawing or tracing the features. It is the process by which coordinates from a map, image, or other sources of data are converted into a digital format in the GIS.

Feature:
A representation of a real-world object on a map.

Layer:
The visual representation of a geographic dataset in any digital map environment. Conceptually, a layer is a slice or stratum of the geographic reality in a particular area, and is more or less equivalent to a legend item on a paper map. On a road map, for example, roads, national parks, political boundaries, and rivers might be considered different layers.

Shapefile:

A shapefile is a digital vector storage format for storing geometric location and associated attribute information. Shapefiles spatially describe geometries: points, polylines, and polygons.

Web app and web maps:

A web map is created and stored in ArcGIS Online. It is a way of displaying information on a web hosted map. The map usually contains a basemap, a set of data layers, navigation/extent tools and simple tools for interacting with the map data.

Web maps are used/embedded within the web apps which may offer additional functionality for interacting with the map. Web apps are a suite of configurable templates which can combine maps, text or other content to build tools such as the UST Reporting Portal for data collection and visualisation.

These applications are accessed through the internet and do not need to be downloaded.

Widget

An interactive graphic component of a user interface (such as a button, scroll bar, or menu bar), its controlling program, or the combination of both the component and program. The widget supports user interaction with the map or data. For example, a zoom widget allows users to interact with the level of detail shown on a map or scene; a legend widget displays information about the data layers.

Appendix 2: Definitions of potentially ambiguous terms:

Pre-advice visits – visits to a land unit or land unit manager (e.g. farmer) undertaken as part of UST3, prior to providing any advice or management plans and before any interventions have been undertaken on that land unit. No advice is given on these visits. In some cases, advice might be given on the first visit, in which case the count for that land unit would always remain zero; this is fine.

Advice-giving or implementation visits – visits undertaken for the purposes of giving UST3 advice (including management plans) and/or undertaking (or advising/helping in the undertaking) of a UST3 intervention. e.g. Where a delivery partner goes to a site in order to participate or advise on tree planting or habitat management that is taking place on the day of the visit. *Note: for the purposes of UST3 reporting the counts for 'advice-giving or implementation visits' and 'maintenance or follow-up visits' are mutually exclusive – a visit should not be input to both categories as this would cause double-counting.*

Maintenance or follow-up visits – UST3 visits to a land unit or land unit manager (e.g. farmer) undertaken where:

i) advice or new management plans have previously been given, or intervention(s) have been implemented or are ongoing; and
ii) no completely new advice is given; and
iii) the purpose of the visit is not to implement an intervention

Note: for the purposes of UST3 reporting the counts for 'advice-giving or implementation visits' and 'maintenance or follow-up visits' are mutually exclusive – a visit should not be input to both categories as this would cause double-counting. If a visit occurs where an intervention or new management practice is ongoing and additional advice is provided about this, then the visit should be counted as a 'maintenance or follow-up visits'. If, however, an intervention or new management practice is ongoing but completely new advice is given (i.e. that relates to a different type of intervention not previously advised on that land unit) then the visit should count as an 'advice-giving or implementation visit'.

Engaged/Engagement – A farm/land unit should be considered engaged in UST when:

i) positive contact has been made with the farmer/landowner
ii) a physical visit has taken place and
iii) there is an expectation that there will be further participation in UST (additional visits, farm plan etc)

At this point GDPR should be completed and the Joint data controller Privacy Notice issued to the farmer/landowner, allowing their details to be entered into the portal.

Appendix 3: Drivers and interventions information

Driver	Explanation	Does this driver have a related monthly reporting item? Will use of this driver feed the intervention into one of the monthly reporting items?
Creation of new permanent habitat*	Actions to create new permanent habitat with the intention that it becomes semi-natural over time. Includes new hedgerows, heathland restoration, turning agricultural improved grasslands into species rich ones, etc. For woodland include new plantings of broadleaves, but not commercial conifers or Willow planted for regular harvesting.	Yes, in the case of Polygon Interventions and Field Parcel Interventions. The "Area of new habitat" reporting item is the total area of polygons in the Polygon Interventions layer and Field Parcel Interventions layer with an intervention driver attribute-field set to "Creation of new permanent habitat". If a Line Intervention driver is given this driver, it cannot contribute to "Area of new habitat" as line interventions are not given an area. However, it is still important to assign this driver if appropriate, to aid categorisation and analysis of interventions. If a Line Intervention (e.g. 'Install non-watercourse fencing') is undertaken as part of creation of new habitat, then the area of habitat created should be captured separately as a Polygon or Field Parcel Intervention.
Restoration of semi-natural habitat*	Actions to improve the ecological function of permanent semi-natural habitat areas. This would include ditch blocking, scrub clearance and introduction of new grazing, etc. But it would not include an annual hay meadow cut, which is part of the annual maintenance cycle. For hedges it would include a restoration project such as laying a neglected hedge but not a bi-annual cut.	Yes, in the case of Polygon Interventions and Field Parcel Interventions. The "Area of habitat restored" reporting item is the total area of polygons in the Polygon Interventions layer and Field Parcel Interventions layer with an intervention driver attribute-field set to "Restoration of semi-natural habitat". If a Line Intervention is given this driver, it cannot contribute to "Area of habitat restored" as line interventions are not given an area. However, it is still important to assign this driver if appropriate, to aid categorisation and analysis of interventions. If a Line Intervention (e.g. 'Install non-watercourse fencing') is undertaken as part of habitat restoration work, then the area of habitat restored should be captured separately as a Polygon or Field Parcel Intervention.

New non-permanent management in the farmed landscape which improves biodiversity*	Includes planting herbal leys, field margins and buffers, actions to encourage arable weeds, fallow periods, etc. All are transient changes as part of the agricultural rotation and not likely to remain as permanent changes in the landscape. Include buffer strip on field edges, don't include fenced off riparian margins, these are new permanent habitat features.	Yes, in the case of Polygon Interventions and Field Parcel Interventions. The "New non-permanent management in the farmed landscape which improves biodiversity" reporting item is the total area of polygons in the Polygon Interventions layer and Field Parcel Interventions layer with an intervention driver attribute-field set to "Restoration of semi-natural habitat". If a Line Intervention is given this driver, it cannot contribute to the area of "New non-permanent management in the farmed landscape which improves biodiversity" as line interventions are not given an area. However, it is still important to assign this driver if appropriate, to aid categorisation and analysis of interventions. If a Line Intervention (e.g. 'Install non-watercourse fencing') is undertaken as part of new management in the farmed landscape which improved biodiversity, then the area of land managed/improved should be captured separately as a Polygon or Field Parcel Intervention.
NFM	Natural Flood Management. Measures aimed at delaying water, reducing surface run-off, and increasing infiltration.	Yes, in the case of Polygon Interventions and Field Parcel Interventions. The "Area of landscape managed for NFM" reporting item is the total area of polygons in the Polygon Interventions layer and Field Parcel Interventions layer with an intervention driver attribute-field set to "NFM". If a Line Intervention is given this driver, it cannot contribute to the "Area of landscape managed for NFM" as Line Interventions are not given an area. However, it is still important to assign this driver if appropriate, to aid categorisation and analysis of interventions.
GHG emissions	Reduce GHG (greenhouse gas) emissions.	No, there is not a specific monthly reporting item related to this driver. However, it is still important to assign this driver where appropriate, to aid categorisation and analysis of interventions.
Nitrogen	Reduce N pollution through reducing inputs (source), reducing nutrient loss (mobilisation), or capturing nutrients in transport.	No, there is not a specific monthly reporting item related to this driver. However, it is still important to assign this driver where appropriate, to aid categorisation and analysis of interventions.

Phosporus	Reduce P pollution through reducing inputs (source), reducing nutrient loss (mobilisation), or capturing nutrients in transport.	No, there is not a specific monthly reporting item related to this driver. However, it is still important to assign this driver where appropriate, to aid categorisation and analysis of interventions.
Pesticides	Reduce pesticide pollution or the potential harm of pesticides (e.g. pesticide swapping).	No, there is not a specific monthly reporting item related to this driver. However, it is still important to assign this driver where appropriate, to aid categorisation and analysis of interventions.
Dirty water	Reduce volumes of dirty water produced from farmyards and manure heaps and ensure safe storage.	No, there is not a specific monthly reporting item related to this driver. However, it is still important to assign this driver where appropriate, to aid categorisation and analysis of interventions.
Soil/sediment	Reduce sediment pollution by reducing losses (mobilisation) or capturing sediment in transport.	No, there is not a specific monthly reporting item related to this driver. However, it is still important to assign this driver where appropriate, to aid categorisation and analysis of interventions.
Pathogens/FIOs	Reduce FIO/pathogen pollution through reducing inputs (source), reducing nutrient loss (mobilisation), or capturing nutrients in transport.	No, there is not a specific monthly reporting item related to this driver. However, it is still important to assign this driver where appropriate, to aid categorisation and analysis of interventions.

*

Please note that these three drivers ('Creation of new permanent habitat, 'Restoration of semi-natural habitat' and 'New non-permanent management in the farmed landscape which improves biodiversity') are mutually exclusive. Each of these three drivers will correspond to a separate reporting item in the Reporting Download spreadsheet. So if a Polygon or Field Parcel intervention is assigned one of these drivers, its area will contribute to the corresponding reporting item (e.g. a polygon with the ‘Creation of new permanent habitat’ driver will contribute to the ‘Area of new habitat’ reporting item). A single intervention should not be assigned more than one of these drivers as this would lead to double-counting in the 'Areal Biodiversity' reporting items.

Appendix 4: Intervention Feature Types and drivers for reporting

Point Intervention Features

Intervention	Description/Explanation	GIS Layer (layer name on the Interventions tab)	Driver (to ensure feeds through into reporting) / Reporting item information where relevant
Construct bridges/watercourse crossings for livestock	This intervention provides a dedicated bridge or crossing point for livestock and machinery. This reduces disturbance to the watercourse, preventing faecal contamination and sedimentation. Relevant CS code: RP3	Point Interventions	No drivers required - point interventions aren't assigned drivers
Installation of cross drains	This item will provide a drain to intercept and conduct surface runoff away from farm tracks and yards. The drain will help reduce channelling of surface runoff and the risk of sediment and other pollution entering a watercourse. Relevant CS code: RP5	Point Interventions	No drivers required - point interventions aren't assigned drivers
Installation of piped culverts in ditches	This watercourse crossing will provide access for farm machinery or livestock. This will reduce the disturbance to the watercourse which will help reduce sedimentation and bacterial levels in the water. If successful there will be: an adequate flow of water; runoff of expected flows diverted under a track so farm machinery and livestock can cross; farm machinery or livestock crossing tracks safely Relevant CS code: RP6	Point Interventions	No drivers required - point interventions aren't assigned drivers

Installation of livestock drinking troughs (in draining pens for freshly dipped sheep)	This item will install new livestock drinking troughs in relocated sheep dip facilities. Pollution from sheep dips can cause damage to people and aquatic wildlife. Relocating sheep dips and pens can help reduce risk of diffuse water pollution. Relevant CS code: RP23	Point Interventions	No drivers required - point interventions aren't assigned drivers
Gateway relocation from high risk area	This option is to move the gateway to a suitable location where it will not act as a pathway for water runoff. This will prevent polluted surface water from leaving fields through gateways and help to reduce risk of soil erosion and diffuse pollution. Relevant CS code: RP2	Point Interventions	No drivers required - point interventions aren't assigned drivers
Construct livestock drinkers/feeders with hard bases	This item will provide hard bases where livestock can stand when drinking. This will reduce the risk of runoff and water pollution from mobilised sediments and organic manures. CS Code: LV3	Point Interventions	No drivers required - point interventions aren't assigned drivers
Installation of secure holding areas to keep dipped sheep away from watercourses	This ensures freshly dipped sheep can be kept in secure areas or fields with no access to a watercourse to reduce risk of watercourses becoming polluted.	Point Interventions	No drivers required - point interventions aren't assigned drivers
Provision of alternative drinking water for livestock - e.g. troughs. Includes associated pipework and pumps.	When cattle have been excluded from watercourses, this is the alternative drinking provided. This item will provide livestock with an alternative to drinking from watercourses and ponds. It will reduce bank erosion, sediment pollution and the faecal contamination of watercourses. It is not for replacing existing troughs. CS code: LV7	Point Interventions	No drivers required - point interventions aren't assigned drivers

Installation of water gates	This item will prevent livestock from entering watercourse channels. It will also stop livestock from trampling waterside banks and will leave bankside vegetation lush and unbroken by livestock paths. FG15	Point Interventions	No drivers required - point interventions aren't assigned drivers
Installation of sheep dip drainage aprons and sumps	It will install a new sheep dip drainage apron and sump in new locations. Pollution from sheep dips can cause damage to people and aquatic wildlife. Relocating sheep dips and pens can help reduce risk of diffuse water pollution Relevant cs code: RP22	Point Interventions	No drivers required - point interventions aren't assigned drivers
Relocation of sheep dips to lower risk locations	CS code: RP20 This item will install replacement sheep dips in new locations. Pollution from sheep dips can cause damage to people and aquatic wildlife. Relocating sheep dips can help reduce the risk of diffuse water pollution.	Point Interventions	No drivers required - point interventions aren't assigned drivers
Resurfacing of gateways	This item will provide a strengthened surface at the field gateway. This will reduce ponding on either side of the gateways caused by soil compaction. If successful there will be reduced surface runoff, soil erosion and risk of diffuse water pollution. Relevant CS code: RP1	Point Interventions	No drivers required - point interventions aren't assigned drivers
In-stream NFM measures	Various features that aim to slow the movement of water in small natural streams and ditches. These features slow surface water, allowing sediment (and other pollutants) to settle out, improving water quality are reducing downstream flood risk. They can also help push lows onto the floodplain. e.g. Check dams, large and small leaky woody dams CS codes: RP12, RP32, RP33	Point Interventions	Point interventions aren't assigned drivers. However, this item automatically feeds into the 'Number of in-stream NFM measures delivered' reporting item.
Other - Custom intervention	Add in an explanation of the intervention delivered.		No drivers required - point interventions aren't assigned drivers

Line Intervention Features

Intervention	Description/Explanation	GIS Layer (layer name on the Interventions tab)	Driver (to ensure feeds through into reporting) / Reporting item information where relevant*
Ditch management	This item is intended for ditch management that has benefits to biodiversity, water quality and/or flood management. This includes management of ditches that are managed as wet farmland features, permanently or seasonally flooded and which support a range of farmland wildlife, including plants, invertebrates, amphibians, reptiles, birds and mammals. Also applies to management of ditches essential for the management of habitats such as wet grassland, fen, reedbed and lowland raised bog. Relevant CS code: WT3.	Line Interventions	This item feeds into the 'Ditch management' reporting item, regardless of which drivers are set.
Hedgerow management - non-riparian	This item is for management of non-riparian hedgerows. It covers various management options including gapping up and laying. Management should increase the availability of blossom for invertebrates. By allowing fruit and berries to ripen it provides food for overwintering birds. It also improves the structure and longevity of hedgerows by promoting vigorous regrowth and a continuous length. If successful there will be: taller and wider hedges, with gaps forming less than 10% of the hedge length. Includes Stone-faced bank repair. Relevant CS codes: BE3, BN7, BN5, BN1, BN2.	Line Interventions	This item feeds into the 'Length of hedgerows (riparian and non riparian)' reporting item, regardless of which drivers are set.

* For Line Interventions, the intervention drivers do not influence which reporting item(s) an intervention feeds into. However, relevant drivers should still be set.

Hedgerow management - riparian	This item is for management of riparian hedgerows. It covers various management options including gapping up and laying. Management should increase the availability of blossom for invertebrates. By allowing fruit and berries to ripen it provides food for overwintering birds. It also improves the structure and longevity of hedgerows by promoting vigorous regrowth and a continuous length. If successful there will be: taller and wider hedges, with gaps forming less than 10% of the hedge length. Relevant CS codes: BE3, BN7, BN5	Line Interventions	This item feeds into the 'Riparian hedgerows' and 'Length of hedgerows (riparian and non riparian)' reporting items, regardless of which drivers are set.
Establish new hedges - non-riparian	This item is for establishing new non-riparian hedgerows. There will be new lengths of hedgerow planted with locally occurring native species. Can be used to replace former hedges, extend or link existing lengths of hedgerow or where creation will help reduce soil erosion and runoff. Relevant CS Code: BN11	Line Interventions	This item feeds into the 'Length of hedgerows (riparian and non riparian)' reporting item, regardless of which drivers are set.
Establish new hedges - riparian	This item is for establishing new riparian hedgerows. There will be new lengths of hedgerow planted with locally occurring native species. Can be used to replace former hedges, extend or link existing lengths of hedgerow or where creation will help reduce soil erosion and runoff. Relevant CS Code: BN12	Line Interventions	This item feeds into the 'Riparian hedgerows' and 'Length of hedgerows (riparian and non riparian)' reporting items, regardless of which drivers are set.
Management of livestock and machinery hardcore tracks	Relocating or resurfacing farm tracks can reduce soil compaction and erosion caused by livestock and machinery. They also help reduce channelling of surface runoff and the risk of sediment and other pollutants entering a watercourse. Relevant CS Code: RP4	Line Interventions	This item feeds into the 'Farm tracks' reporting item, regardless of which drivers are set.

Install watercourse fencing	Trampling by livestock can erode river/stream banks and increase sediment inputs to watercourses. Preventing access eliminates this source of pollution. Keeping stock out of watercourses and off banks adjacent to watercourses also avoids direct contamination of water with soil and faeces.	Line Interventions	This item feeds into the 'Riverside Fencing' reporting item, regardless of which drivers are set.
Install non-watercourse fencing	Fencing to control livestock and protect environmental features or habitat. For example, post and wire, sheep netting, electric fencing etc. Relevant CS Codes: FG1, FG2, FG3	Line Interventions	Please select relevant drivers. However, this intervention will not feed into a monthly reporting item.
Stone wall restoration	There will be a rebuilt stone wall which will help to control livestock and conserve traditional landscapes. Relevant CS code: BN12	Line Interventions	Please select relevant drivers. However, this intervention will not feed into a monthly reporting item.
Establish in-field grass buffer strips	Grass areas or strips will help to reduce the quantity of sediment, nutrients and pesticides transported through surface runoff water, both within fields and from field to field. A grass buffer strip may provide new habitat, protect existing landscape features, and improve water quality. Next to existing features, it will provide habitat for wildlife, and form links or corridors between other habitats. Relevant cs codes: SW1, SW3	Line Interventions	This item feeds into the 'In-field grass buffer strips' reporting item, regardless of which drivers are set.
Establish riparian buffer strips	It establishes a grass buffer to help reduce the risk of potential pollutants, such as sediment, pesticides and nutrients (mainly phosphate), being transported to watercourses in surface water runoff. It may also provide habitat for wildlife, and form links between other habitats. Relevant cs code: SW4	Line Interventions	This item feeds into the 'Riparian buffers created' reporting item, regardless of which drivers are set.
Other - Custom intervention	Add in an explanation of the intervention delivered.		Please select relevant drivers.

Polygon Intervention Features

Intervention	Description/Explanation	GIS Layer (layer name on the Interventions tab)	Reporting Driver (to ensure feeds through into reporting)[*] / Reporting item information where relevant
Creation of beetle bank	There has been creation of a raised grass bank to provide nesting and foraging for insects, small mammals and birds. Relevant CS code: AB3	Polygon Interventions	New non-permanent management in the farmed landscape which improves biodiversity
Creation of wet/water holding features	This option includes various features designed to permanently or seasonally hold water for the benefit of invertebrates and/or wading birds (e.g. scrapes and gutters, foot-drains, ponds/pools) and/or managing run-off, sediment or water pollution (e.g. swales, sediment traps and ponds). Relevant CS codes (list may not be exhaustive): WN2, RP7, RP11	Polygon Interventions	Creation of new permanent habitat and/or NFM (could be appropriate depending on the intervention)
Management of in-field wet /water holding features	This option includes various features designed to seasonally hold water for the benefit of invertebrates and/or wading birds (e.g. scrapes and gutters, foot-drains, ponds/pools) and/or managing sediment or water pollution (e.g. swales, sediment traps and ponds). Relevant CS codes (list may not be exhaustive): WN5, WN6, WT4, WT5, WN7	Polygon Interventions	Restoration of semi-natural habitat and/or NFM (could be appropriate depending on the intervention)

[*] Only drivers that directly feed into monthly reporting items are listed. However, it is important that other drivers are also selected where relevant, to aid additional categorisation, analysis and reporting of interventions.
There are three habitat/biodiversity drivers that, in the case of Polygon and Field Parcel Interventions, feed into monthly reporting items:
If the "**Creation of new permanent habitat**" driver is set, the area of a Polygon or Field Parcel Intervention will feed into the "Area of new habitat" monthly reporting item.
If the "**Restoration of semi-natural habitat**" driver is set, the area of a Polygon or Field Parcel Intervention will feed into the "Area of habitat restored" reporting item.
If the "**New non-permanent management in the farmed landscape which improves biodiversity**" driver is set, then the area of a Polygon or Field Parcel Intervention will feed into the "New non-permanent management in the farmed landscape which improves biodiversity" reporting item.
There is one additional driver that, in the case of Polygon and Field Parcel Interventions, will feed into a monthly reporting item:
If the "**NFM**" driver is set, then the area of a Polygon or Field Parcel Intervention will feed into the "Area of landscape managed for NFM" monthly reporting item.

Creation of successional areas and scrub	This option regenerates a succession of scrub. This enhances habitats for specific target species and improves the quality of the woodland edge. Relevant CS code: WD8	Polygon Interventions	Creation of new permanent habitat or New non-permanent management in the farmed landscape which improves biodiversity
Management of successional areas and scrub	This option provides enhanced habitat for a wide range of wildlife and improves the quality of the woodland edge. It also helps prevent soil erosion and holds back water to reduce downstream flood risks. Relevant CS code: WD7.	Polygon Interventions	Restoration of semi-natural habitat or New non-permanent management in the farmed landscape which improves biodiversity
Establishment of legume and herb-rich swards	This is creation of a vigorous, mixed sward with abundant grasses, legumes, herbs and wildflowers, suitable for productive cattle and sheep, which will also provide habitat and food for invertebrates, including crop pollinators, and improve soil structure and water infiltration. Relevant CS code: GS4	Polygon Interventions	New non-permanent management in the farmed landscape which improves biodiversity
Management of moorland – re-wetting (e.g. ditch blocking drainage channels)	This includes activities to maintain and restore moorland habitats and ecosystem function. Including actions to re-wet. Relevant CS code: UP3 (and UP5, Moorland rewetting)	Polygon Interventions	Restoration of semi-natural habitat. NFM driver could be relevant.
Management of moorland vegetation	This option is for when an appropriate programme of vegetation management has been implemented to contribute to restoration and improvement in the functionality of priority habitats such as dry heath, wet heath and blanket bog where significant changes to current management are required. Relevant CS code: UP3, UP4	Polygon Interventions	Restoration of semi-natural habitat

Creation of fallow plots for lapwing and/or stone-curlew nesting	This option aims to provide sparsely vegetated/fallow plots as nesting sites for lapwing and other ground-nesting birds in large arable fields. Relevant CS code: AB5	Polygon Interventions	New non-permanent management in the farmed landscape which improves biodiversity
Plant areas of farm with wild bird seed / nectar flower mixtures	This option provides areas of flowering plants to boost essential food sources for beneficial pollinators and farmland birds, especially in autumn and winter. Relevant CS Codes: AB1, AB8, AB9	Polygon Interventions	New non-permanent management in the farmed landscape which improves biodiversity
Protection of in-field trees	This option aims to protect trees (including roots) from agricultural operations. Fallen trees will be left to provide habitats for invertebrates. Relevant CS Code: BE1	Polygon Interventions	New non-permanent management in the farmed landscape which improves biodiversity
Creation of new BAP habitat	This option is where there is an opportunity for habitat creation (or re-creation) of a specific priority habitat. Details of before and after habitat should be recorded.	Polygon Interventions	Creation of new permanent habitat
Creation of new habitat (non-BAP)	This option is where there is an opportunity for habitat creation (or re-creation) of a non-BAP habitat. Details of before and after habitat should be recorded.	Polygon Interventions	Creation of new permanent habitat
Enhancement of BAP habitat	This option is where there is an opportunity for enhancement of a BAP habitat. Habitat type should be recorded.	Polygon Interventions	Restoration of semi-natural habitat or New non-permanent management in the farmed landscape which improves biodiversity (for Field Margins only)
Enhancement of habitat (non-BAP)	This option is where there is an opportunity for enhancement of a non-BAP habitat. Habitat type should be recorded.	Polygon Interventions	Restoration of semi-natural habitat or New non-permanent management in the farmed landscape which improves biodiversity
Creation of new skylark plots	This option creates Skylark plots - bare patches in winter cereal fields designed to help skylarks to forage. Relevant CS code: AB4	Polygon Interventions	New non-permanent management in the farmed landscape which improves biodiversity

Tree planting	This option is for capital spend on individual tree planting, or restocking after tree health issues. (Woodland planting should be recorded as Creation of new habitat). Relevant CS code TE4.	Polygon Interventions	No biodiversity driver might be appropriate (e.g. just planting a couple of trees) or Restoration of semi-natural habitat N.B. 'Creation of new permanent habitat' driver not appropriate because woodland creation should be entered under a creation of new habitat intervention
Take field corners and small areas out of management	Field corners and other small areas can be taken out of management/production (on both arable and livestock farms) by either not managing or planting with grass which will create year round habitat and food for a range of wildlife. Relevant CS Code: GS1	Polygon Interventions	New non-permanent management in the farmed landscape which improves biodiversity
Create or maintain unharvested cereal headlands	This intervention creates conservation headlands/headlands of cereal crops which are sprayed selectively to allow populations of broad-leaved weeds and their insects to develop. Management involves avoiding the use of broad-leaved herbicides in the crop, and avoiding the use of insecticides. It will provide an important food source for farmland birds throughout the year and insects in the summer, and provides both grain and seeding arable plants in winter. Relevant CS code: AB10	Polygon Interventions	New non-permanent management in the farmed landscape which improves biodiversity

Seasonal exclusion of livestock from upland sites	This intervention excludes livestock from upland sites (for at least 4 months) in order to improve habitat and feature conditions. This intervention should allow: increased rates of heather regeneration; improved rates of flowering of rare species such as spring gentian; a regeneration of scrub such as juniper; improved downstream water quality and improvements in the condition and visibility of archaeological sites and other historic features. Relevant CS code UP6	Polygon Interventions	New non-permanent management in the farmed landscape which improves biodiversity
Establish tree shelter belts around livestock housing and/or slurry storage facilities	For the purpose of recapture of ammonia emissions from animal housing units or slurry stores. Tree shelter belt will disrupt air flows around the building or slurry storage facility, reducing NH3 emission rates and will also directly re-capture a proportion of the emitted NH3. New or increased wooded habitat created (both broadleaved and conifers) would increase biodiversity.	Polygon Interventions	Could potentially be assigned 'Creation of new permanent habitat'
New roofing	This item will provide new roofing to reduce water pollution by preventing rainfall from getting into: sprayer washdown areas manure storage areas livestock gathering areas slurry and silage stores	Polygon Interventions	This item feeds into the 'New roofs and concrete yards' reporting item, regardless of which drivers are set.

	Relevant CS code: RP28		
Yard works and rainwater goods	These measures aim to improve or upgrades existing outdoor (uncovered) yards and yard drainage to reduce foul drainage volumes (by collection of water and keeping clean and dirty water separate), reduce runoff and risk of water pollution. Actions include: concrete yard renewal, yard inspection pits, rainwater goods, rainwater storage tanks, pipework/separation of clean and dirty water from farm yards and roofs/ inspection pit/chamber. Relevant CS codes: RP13, RP14, RP15, RP16, RP17, RP18, RP19	Polygon Interventions	This item feeds into the 'New roofs and concrete yards' reporting item, regardless of which drivers are set.
Site solid manure heaps on concrete/impermeable base and collect the effluent	If stored directly on the soil surface, leachate from solid manure heaps will seep into the soil and/or flow over the soil surface in response to rainfall events. Storing manure on an impermeable base prevents the seepage and accumulation of nutrients in the soil below the heap, which may subsequently be lost in surface runoff/drain flow or leaching to ground water. Also, storage on an impermeable (e.g. a concrete base) reduces soil compaction caused by farm machinery, during the forming and subsequent spreading of field heaps. The leachate collected can be spread at a later date when soil conditions are suitable and the nutrients can be utilised by crops, or the leachate may be added back to the heap or into a slurry store.	Polygon Interventions	This item feeds into the 'New roofs and concrete yards' reporting item, regardless of which drivers are set.

Earth banks and soil bunds	An earth bank or soil bund can be used to: - slow the movement of water, protecting streams and rivers from pollutants - slow flows during high rainfall and reduce downstream flooding - control water levels to aid raised water levels for habitat creation and restoration CS code: RP9	Polygon Interventions	NFM
Making space for water	This measure will help water flow in a winding course across floodplains, flooding temporarily to restore river and wetland habitats. This will also reduce the risk of high energy flows and soil erosion, and allow water to drain freely back into the river channel. If successful there will be: - new areas of river and wetland habitats appearing, such as new channels, temporary ponds in old channels and wet grassland - gradual erosion and movement of the river bed and river banks - deposits of gravel, sand and silt appearing in the river channel and on the floodplain after a flood CS code: SW12	Polygon Interventions	NFM
Other - Custom intervention	Add in an explanation of the intervention delivered.		Please select relevant drivers.

Land Unit Point Intervention features

Intervention	Description/Explanation	GIS Layer (layer name on the Interventions tab)	Driver (to ensure feeds through into reporting)
Ensure irrigation/water supply equipment is maintained and leaks repaired	This advice measure aims to improve water use efficiency.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use efficient irrigation techniques (boom trickle, self-closing nozzles)	This advice aims to promote use of efficient and accurate irrigation techniques for water use efficiency.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Adoption of a nutrient management plan	This option is aimed at improving nutrient management planning to develop effective nutrient management ensuring application timings are appropriate and inputs are matched to crop demand thereby minimising use potentially saving costs to the farm and protecting the environment.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Analyse soil nutrient value	This option advises regular soils analysis. Knowledge of soil properties is essential for setting site objectives, and provides a valuable baseline against which trends can be judged and problems diagnosed.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Avoid liming or fertilising marginal land	CSF recommendation to avoid liming or fertilising marginal land.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Avoid spreading manufactured fertiliser to fields at high-risk times (e.g. when risk of run-off is high)	Fertiliser timing affects the mobilisation of nutrients released from land to water. Avoiding spreading to fields at high-risk times reduces the availability of nitrate for loss through leaching and of P for loss in surface run-off or rapid preferential flow.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Do not apply manufactured fertiliser to high-risk areas (e.g. high risk of run-off)	This recommendation advises consideration of high risk areas and suggests fertilisers are not applied if there is a high risk of run-off, taking account of the slope of the land, land drains, ground cover, proximity to surface water, weather conditions and soil type.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Do not apply P fertilisers to high P index soils	The amount of P lost via soil erosion or leaching depends on the soil P status. Losses in solution increase rapidly once soil P reserves reach elevated levels (e.g. ADAS Soil P index 4 or above). Losses can be minimised by maintaining soil P levels at Index 2 or by allowing the P content of high P index soils to run-down overtime.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Fertiliser spreader calibration (includes re-calibrate after testing)	Inaccurate fertiliser spreading (i.e. poor spread patterns) results in the under-application of fertiliser on some areas and over-application on other areas. Under-application of N fertiliser results in reduced yields and over-application can also result in reduced yields (through lodging) and increased NO3 leaching losses.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Incorporate a urease inhibitor into urea fertiliser	Urea and urea-based fertilisers are associated with much higher ammonia emissions than other types of nitrogen fertiliser. Urease inhibitors delay the conversion of urea to ammonium carbonate; this delay allows urea fertiliser to be solubilised and 'washed' into the soil and also reduces the pH rise around the urea fertiliser.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Integrate fertiliser and manure nutrient supply	Recommendation systems should be used to provide a robust estimate of the amount of nutrients supplied by organic manure applications. This information can then be used to determine the amount and timing of additional manufactured fertilisers needed by the crop. Fertiliser use statistics suggest that, in many cases, this will result in a reduction in fertiliser inputs (particularly on arable and maize crops) compared with current practice and a concomitant reduction in diffuse nutrient pollution.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Monitor grain nitrogen content and adapt nitrogen applications	To adapt N applications to specific requirements of the crops.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Reduce fertiliser application rates	Better planning and calculation of requirements can allow reductions in application rates.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Replace urea fertiliser with another nitrogen form (e.g. ammonium nitrate)	Urea and urea-based fertilisers are associated with higher NH_3 emissions (typically around 20% of total N applied for urea and 10% for UAN) than other forms of manufactured fertiliser N.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use (manufactured) fertiliser placement technologies	Placement of nutrients close to plant seeds and roots increases nutrient uptake efficiency. Fertiliser placement can be particularly useful in low P status soils to increase uptake efficiency and can also enable reductions in fertiliser application rates through improved nutrient recovery (without any impact on yield). Placement also reduces exposure of fertiliser at the soil surface, thereby reducing the potential for incidental losses in surface runoff from sloping ground.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use clover in place of fertiliser nitrogen	By using clover in a grass sward the need for additional manufactured N fertiliser is reduced.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use clover in place of grass	By using clover in a grass sward the need for additional manufactured N fertiliser is reduced.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Use nitrification inhibitors	This measure promotes the addition of nitrification inhibitors (NIs) to applied manufactured N fertilisers, organic manures and grazed pastures for the purpose of slowing the rate of conversion of NH_4 to NO_3, so that NO_3 is formed at a rate that is in better 'synchrony' with crop demand (i.e. slow release) and will thereby increase N use efficiency and reduce N_2O emissions and NO_3 leaching.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use plants with improved nitrogen use efficiency	This measure aims to develop new plant varieties with improved genetic traits for the capture of soil N. Improving N use efficiency of plants could potentially: • Reduce fertiliser N additions to agriculture • Improve nutritional characteristics of new forage plant varieties (e.g. improved amino acid profile, reduced rumen protein degradation, improve fibre digestibility) • Improve N efficiency in agriculture	LU Point	No drivers required - LU point interventions aren't assigned drivers
Very low nitrogen inputs to groundwaters	This will be used to reduce nutrient input to grassland in highly targeted locations to help slow or reverse nutrient levels in groundwater. This will be targeted to help specific designated sites and Water Framework Directive Protected Areas. CS code: SW13	LU Point	No drivers required - LU point interventions aren't assigned drivers
Adopt phase feeding of livestock	This measure aims to: • Manage livestock in smaller groups, divided on the basis of their individual feed requirements. • Feed groups separately with rations matched to the optimum N and P requirements of the animals within each group. This allows more precise matching of the ration to the individual animal's nutritional requirements. Nutrients are utilised more efficiently and less dietary N and P is excreted, thereby reducing the N and P content of manures, which reduces the amount of N and P at risk of loss.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Locate out-wintered stock away from watercourses	This will limit livestock poaching and damage to areas along watercourses and associated pollution.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Move feed and water troughs at regular intervals or install onto permanent hard standing	To avoid poaching of soils where animals gather to feed.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Outwintering of cattle on wood-chip stand-off pads	For cattle, as an alternative to winter housing in a building, construct purpose-built woodchip pads (including an impermeable liner and drainage collection system), with a feeding area. NH_3 emissions from urine deposition on to a woodchip stand-off pad are likely to be lower than from a concrete yard or a cattle house, because of rapid infiltration into the woodchip matrix.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Reduce dietary N and P intakes if too much being given now (includes; Dairy, Pigs, Poultry)	Avoiding excess N and P in the diet and/or making dietary N and P more available allows nutrient concentrations in the diet to be reduced, without adversely affecting animal performance. These methodologies reduce the amount of N and P excreted, either directly to fields or via handled manures, and thereby minimise additions as sources of diffuse pollution.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Reduce field stocking rates when soils are wet	Soils are most easily poached/compacted when they are 'wet'. Reducing livestock numbers or the duration of grazing when soils are 'wet' reduces poaching damage and the potential for mobilisation and transport of pollutants to watercourses.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Reduce overall stocking rates on livestock farms	Reducing the stocking rate reduces the amount of nutrients and FIOs in field deposited excreta and in handled manures at an individual farm level. Associated manufactured fertiliser inputs and poaching risks would also be reduced.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Reduce the length of the grazing day/grazing season	Reduce the length of time livestock graze in the fields, either by keeping stock inside during the night or by shortening the length of the grazing season. Urine patches are a major source of NO3 leaching and N2O emissions to air. Reducing the time animals spend at grazing reduces the amount of urine deposited in fields.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Reduce upland grazing to sustainable levels to prevent erosion	Reducing stocking levels or changing timing can reduce impact on upland vegetation and reduce soil erosion. Especially where soils are already bare (due to fire, bracken control or forestry activities).	LU Point	No drivers required - LU point interventions aren't assigned drivers
Seasonal livestock removal (e.g. on grassland in SDAs next to streams, rivers and lakes)	Livestock will be removed at particular times of the year from fields adjacent to a watercourse that are prone to waterlogging, compaction or poaching. This will help improve soil structure, reduce surface runoff and risk of diffuse pollution to the watercourse. Reducing surface runoff may help to reduce the risk of flooding. Relevant cs code: SW9	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use high sugar grasses	In addition to dietary benefits, HSG's have been found to provide environmental benefits in the form of reduced environmental N losses. Improving protein utilisation in the rumen reduces nitrogen (N) losses in the urine. This in turn, reduces environmental impacts through the decrease in nitrous oxide emissions from converted volatile ammonia in urine.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Additional targeted straw bedding for cattle housing	Increasing targeted straw bedding use (in areas where most excreta is deposited) enhances the physical and microbiological emissions reduction properties of FYM.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Adopt batch storage of slurry (pathogen reduction)	FIOs die-off during storage. However, adding fresh slurry results in re-inoculation with viable microorganisms, so for effective reduction in FIO loads, slurry needs to be batch stored without fresh additions. As there are few microorganisms on the batch stored slurry (after 90 days), the risk of FIOs entering water bodies via surface runoff or drain flow losses (after slurry application) is greatly reduced.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Adopt batch storage of solid manure	FIOs die-off during storage; as a result there will be fewer microbial pathogens in the spread manure and lower loss risks in runoff. Also, the readily available N content of stored farmyard manure (FYM) is lower than in 'fresh' FYM, due to losses during storage, which will lessen the risk of NO_3 leaching losses and NH_3 emissions.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Allow cattle slurry stores to develop a natural crust	Retain a surface crust on stores, composed of fibre and bedding material present in cattle slurry, for as long as possible. In most cattle systems, it is possible to retain an intact crust for the majority of the year. The surface crust acts as a physical barrier between the NH_4-N in slurry and the free air above the crust, and thereby reduces NH_3 emissions.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Analyse slurry and manure for nutrient content	Livestock manure and slurry contain valuable nutrients. Good nutrient management makes the most of these resources, minimises application of mineral fertilisers and reduces nutrient losses. By realising the nutrient content of the manures and slurry on your farm, you can benefit from: - cost savings due to decreased inputs of mineral fertilisers - improved crop yields and quality - reduced risk of watercourse pollution - improved soil fertility and structure - improved habitat and fishery quality.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Assess amount of dirty water returned to land, its nutrition value and volume	Dirty water is a low dry matter effluent made up from water contaminated by manure, urine, effluent, milk, dairy washings or cleaning materials. Assessing volumes and nutrient value will avoid risk of such things as pollution caused by run-off and over will ensure applications are in line with crop requirements and avoid application of N and P.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Change from slurry to a solid manure handling system	Change from a system where the manure from housed animals is collected as a liquid (i.e. slurry) to one where animals are kept on bedding (e.g. straw) to produce solid manure. Solid manures are more easily stored than slurries and present less risk of pollutant loss during and following land spreading. Straw use also encourages bacterial immobilisation of readily available nitrogen, resulting in a lower potential for NH_3 emissions during housing, storage and following land spreading	LU Point	No drivers required - LU point interventions aren't assigned drivers

Change from solid manure to slurry handling system	Change from a system where the manure from housed animals is collected as a solid to one where animals are kept on a liquid (i.e. slurry) based system. Slurry-based systems have a greater risk of pollutant losses during and following land spreading. However, solid manures contain both aerobic (and anaerobic) micro-sites where NH_4-N can be nitrified to NO_3-N, providing a source of NO_3 for N_2O emission (by denitrification). This can occur as the bedding material builds up in the animal house, and particularly once the bedding has been removed from the building for storage prior to land spreading. Slurry, on the other hand, is anaerobic (until the time it is spread onto land) and there is little or no N_2O emission from slurry-based buildings/stores.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Compost solid manure	The aim is to facilitate naturally occurring microflora to degrade cellulose and other carbon compounds in the manure to produce a friable, stable and spreadable material, with reduced volume. As part of the composting process, the manure is 'sanitised' and the readily available N content is reduced, thereby lowering the risks of FIO and NO3 losses when the composted manure is spread to land.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Do not apply manure to high-risk areas (e.g. high risk of run-off)	Do not apply manure to field areas where there is a high-risk of direct loss to watercourses. For example, directly adjacent to a watercourse. These areas have a high-risk of rapid transport of manure-borne pollutants to watercourses, so manure applications (particularly of slurry) should be avoided wherever possible.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Do not spread, farmyard manure, slurry or poultry manure to fields at high-risk times (e.g. when risk of run-off is high)	Slurries and poultry manures have 'high' readily available N contents (>30% of total N). Avoiding the application of these materials at times when surface runoff or rapid preferential flow to field drains is likely to occur reduces water pollution risks. Also, avoiding application in autumn/early winter will help to reduce over-winter NO_3 leaching losses.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Frequent removal of slurry from beneath-slat storage in pig housing	NH_3 emissions from slatted-floor pig housing occur from both manure deposited on slat surfaces and also slurry in the below slatted-floor storage area. Frequent removal of beneath-slat slurry will reduce NH_3 emissions from pig housing.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Incorporate manure into the soil as soon as possible	The rapid soil incorporation of manure can reduce pollutant losses in runoff and also reduce the exposed surface area of manure from which NH_3 emissions can occur.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Increase scraping frequency in dairy cow cubicle housing	More frequent removal of urine and faeces from the cubicle passage floor reduces the amount of time that NH_3 emissions (from a given quantity of excreta) will occur, thereby reducing the overall potential for emissions.	LU Point	No drivers required - LU point interventions aren't assigned drivers
In-house poultry manure drying	Drying will inhibit the hydrolysis of uric acid N in the manure, slowing the formation of NH_4-N and thereby reducing NH_3 emissions	LU Point	No drivers required - LU point interventions aren't assigned drivers
Install air-scrubbers or bio trickling filters in mechanically ventilated pig housing	This method removes NH_3 from the exhaust air-stream, thereby reducing emissions to the wider environment.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Manure spreader calibration (includes re-calibrate after testing)	The even application of manure ensures that all parts of the field receive similar amounts of total and crop available nutrients. The uneven spreading of manure can result in a variable supply of nutrients to the crop that is difficult to take into account as part of the farm nutrient management plan; so farmers tend to fertilise to meet crop nutrient needs on under-applied areas. Over application of N results in higher post-harvest soil mineral N levels and greater potential for NO_3 leaching losses over-winter. Runoff risks would also be reduced.	LU Point	No drivers required - LU point interventions aren't assigned drivers
More frequent manure removal from laying hen housing e.g. with manure belt systems	The method relies on the rapid removal of manure from the house prior to the peak rate of NH3 emission.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Ensure adequate capacity of farm slurry (manure) stores to improve timing of applications	The collection and storage of manure and slurry provides increased flexibility in land application timing. There will be fewer occasions when a lack of storage capacity forces application to occur when here is a high-risk of surface runoff and losses to water i.e. when soils are 'wet'.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Site solid manure heaps away from watercourses and field drains	An adequate separation distance between field heaps and watercourses reduces the risk that any leachate from a heap might run over the soil surface directly into a watercourse. Similarly, siting solid manure heaps away from field drains reduces the risk of preferential flow of leachate through the soil that could transport nutrients, FIOs and oxygen depleting pollution to watercourses. There can be an increased risk of surface runoff from the area immediately surrounding a field heap, because of damage to soil structure caused by farm machinery when loading/unloading manure.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Transport manure to neighbouring farms	Nutrients are removed and exported to neighbouring farmland. This reduces the nutrient load on the farm and thereby reduces the risk of diffuse pollution from that farm. The export of manure should also enable the remaining manure to be managed in a more integrated way i.e. there will be less pressure to spread manures during high-risk periods and to better time applications in relation to crop demand.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use anaerobic digestion of livestock manures	CH4 generated from livestock manures during (mesophilic) anaerobic digestion can be used to produce heat and power, and to replace fossil fuel use. Also, CH4 emissions during subsequent manure storage prior to land spreading will be reduced	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use dry-cleaning techniques to remove solid waste from yards prior to cleaning	Dry-cleaning techniques, such as scrapers, squeegees and brushes, can be used to remove solid waste from yards and pens before they are cleaned with water. This will reduce the amount of water used, as well as the quantity of dirty water requiring treatment, storage and disposal.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use liquid/solid manure separation techniques	Separating the suspended solids from slurry means that the two manure streams can be handled separately. The solid fraction can be stored on a concrete pad or in a field heap, while the liquid fraction can be stored and transported/pumped to fields for land application. Separation enables greater flexibility in manure management and application timing.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use manure additives (e.g. alum)	Use of additives in manure for environmental benefit (e.g. to reduce emission of gases such as ammonia).	LU Point	No drivers required - LU point interventions aren't assigned drivers

Use poultry litter additives	Poultry litter contains 'high' concentrations of P and readily available (uric-acid and ammonium) N. Research has shown that P concentrations in surface runoff are closely related to the soluble P content of the manure. Alum additions to poultry litter precipitate P into a form that is not water-soluble. Also, Alum additions reduce NH3 emissions from poultry litter which can result in heavier birds, better feed conversion efficiency and lower mortality.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use slurry band spreading application techniques	NH_3 volatilisation occurs from the surface of the applied slurry. Reducing the overall surface area of slurry, by application in narrow bands, will lead to a reduction in NH_3 emissions (provided that slurry infiltration into the soil is not delayed by the increased hydraulic loading rate on the slurry bands compared with broadcast spreading). In addition, if slurry is placed beneath the crop canopy, the canopy will also provide a physical barrier to reduce the rate of NH_3 loss.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use slurry injection application techniques	NH_3 volatilisation occurs from the surface of applied slurry. Reducing (for open slot shallow injection) or eliminating (for closed slot deep injection) the surface area of applied slurry reduces NH_3 emissions.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Washing down of dairy cow collecting yards	Urine deposited on collecting yard surfaces is a major source of NH3 emissions. Reducing the quantity of urine on the yard surface and the time it remains there will reduce NH3 emissions.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Adopt and follow a comprehensive integrated pest management plan (IPM).	IPM programs use current, comprehensive information on the life cycles of pests and their interaction with the environment. This information, in combination with available pest control methods, is used to manage pest damage by the most economical means, and with the least possible hazard to people, property, and the environment.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Employ methods to ensure no pesticide spills	Methods for avoiding any pesticide spill (concentrate or tank mix) - including tank overfilling. Use portable bund or drip tray to place underneath hopper to catch spillages. Do not wash any spill into drains - Use absorbent spill kits/provide bucket of sand for use	LU Point	No drivers required - LU point interventions aren't assigned drivers
Avoid plunge dipping of sheep - use only 'pour-ons' and 'injectables' for external sheep parasites.	Consider alternative treatment methods such as pour-on or injectable products instead of lunge dips as it is easier to minimise exposure of people and protect the environment.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Avoid PPP application at high risk timings (e.g. immediately prior to significant rain, windy and frosty conditions)	Avoiding the application of these materials at times when surface runoff or rapid preferential flow to field drains is likely to occur reduces water pollution risks.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Effective treatment of PPP washings through disposal, activated carbon or biobeds / biofilters (or other technology)	Pesticide contaminated water produced during sprayer cleaning can cause pollution problems. Bioremediation options such as biobeds/biofilters provide controlled areas for these liquids to enter a biomix where any pesticides within the waste liquid can lock onto organic matter. Bacteria within the biomix then slowly work to break down the pesticide residues.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Ensure safe and appropriate on-farm storage and disposal of pesticide products	Preventing accidents/ leaks/ fire (HSE AIS 16).	LU Point	No drivers required - LU point interventions aren't assigned drivers

In-field preparation and calibration of applicator/sprayer	PPPs can enter surface water bodies through different routes. Most important are the losses of PPPs from point sources (originating from the farmyard) and diffuse sources (originating from treated fields, e.g. surface runoff/soil erosion, drainage and spray drift). Filling and cleaning in the field to be treated can reduce the risk of spills in the yard, or whilst travelling to the field and avoids contaminated mud being carried out of fields on to roads. However locations should be alternated and keep a distance of at least 10m from a watercourse.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Leave residual levels of non-aggressive weeds in crops	Residual weed populations in crops provide food for farmland birds, mammals and invertebrates. This also reduces levels of pesticide and herbicide use.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Spray headland last to avoid driving on treated area.	Spraying headlands last helps to avoid driving over sprayed areas and picking up mud and pesticides on tyres, reducing the risk of pollution.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Store sprayers and pellet applicators under cover to prevent wash off losses with rain.	Storing sprayers and applicators under cover whilst not in use will reduce any risk of wash off by rain and protect watercourses.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Substitution of one pesticide for an alternative(s) with beneficial properties (e.g. lower use rate/ no detections in water/ easier drinking water removal).	Use of alternative pesticides (e.g. ones whose physio-chemical properties make it less mobile in soil) is a useful method of mitigating risk of pesticides to surface waters.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use high quality best practice 'in field' sprayer/pellet operations. E.g. avoid all watercourses	Follow best practice for applications including consideration of application variables such as height and speed of sprayer, sprayer calibration, filling and timing off application and keep away from water courses.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Provide high quality training for spray operators.	Pesticides are hazardous and must be handled responsibly and with care. Operators should be aiming to maximise the benefit whilst minimising the risk to themselves, bystanders and the environment. To make sure this happens, pesticide legislation in the UK regulates not just the products themselves but also the people who handle and use them. All pesticide users must be adequately trained, no matter what their age. The training should give them the same skills needed to obtain a Certificate of Competence. All contractors who apply professional pesticides must hold a certificate of competence.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use improved PPP application technology	The adoption of new methods and application technologies can have many benefits. Such improvements as more accurate and consistent application of chemicals (using variable rate sprayers or spot spraying for example) makes application of PPP more targeted and reduces the risk of over-/under-dosing over blanket spraying methods and reduces overlaps. This provides cost efficiencies and a reduction in pesticide use - getting the same affect with less pesticide.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use professional spray contractors	Use professional spray contractors registered with an appropriate trade body to apply pesticides using best or ideal practice (e.g. NROSO). Specify a contractor who recognises and acts on pesticides in water advice.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Adopt soil management plan	Managing soils according to a carefully considered and updated plan can help to reduce the risk of compaction and erosion, optimise the yields and quality of crops and pasture, as well as reducing the risk of damaging the environment.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Adopt reduced cultivation systems where soils are suitable	Reduced/no-till cultivations (rather than ploughing) can retain soil surface organic matter and preserve good soil structure, with the resulting soil conditions improving water infiltration rates and thereby reducing soil erosion risks and associated loss risks of particulate P and sediment.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Allow field drainage systems to deteriorate where being allowed to cease drainage	Drainage systems can accelerate the delivery of pollutants from land to a watercourse, by acting as a preferential (by-pass) flow route. Allowing drainage systems to deteriorate therefore reduces hydrological connectivity and the potential transfer of pollutants to watercourses, although surface runoff would be increased.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Avoid high risk crops on fields at high risk of erosion	This is primarily to manage soil erosion. For example, switching from late sown autumn to spring sown crops on higher risk sites, the likelihood of erosion can be reduced significantly.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Check for and deal with capping and sub-surface compaction	This will identify problems and allow them to be dealt with and chose appropriate actions for future use. Good soil structure is important as it affects such things as run-off and erosion and nutrient loss.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Cultivate and drill across the slope (where it is safe to do so)	On fields with simple slope patterns, cultivating and drilling across the slope will reduce the risk of surface runoff being initiated and increase re-deposition rates where surface runoff does occur. The ridges created across the slope increase down-slope surface roughness and provide a barrier to surface runoff. As a result, particulate P and associated sediment losses will be reduced.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Ensure properly managed heather/grass burns (cf: Defra code of good practice) to prevent damage to soil	Follow guidance and consider avoiding sensitive areas such as woodland edges, peatlands, areas where the soil is very thin or there is already soil erosion, steep hillsides and areas near watercourses. Aim to conduct "quick, cool burns" as these pose less risk of damage to the moss or litter layer and exposure of base soil.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Purchase of equipment to disrupt tramlines in arable areas	This option is for the purchase of equipment that can loosen soil that has compacted in wheeled tramlines. E.g. Spiked or rotary harrow or tine device. CS: RP31	LU Point	No drivers required - LU point interventions aren't assigned drivers
Harvest high risk fields (or medium risk fields with high risk crops) early in autumn and introduce cover crop	Earlier harvesting of crops, especially those that are traditionally harvested late, would enable harvesting to be undertaken when soil conditions were drier, reducing (severe) compaction and soil structural damage risks, and associated sediment and nutrient losses in surface runoff. Introducing a cover crop would enable the crop to take up (some) N before the onset of over-winter drainage and provide good vegetation cover over the winter months to protect the soil from rainfall induced surface runoff and associated erosion.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Introduce grass leys into arable rotations	A herbal ley is a diverse sward that includes different grasses and species, with varying rooting depths, properties and drought tolerances. They have a positive effect on soil health, structure and drainage and usually include nitrogen-fixing legumes, which are high in protein and tannins, and have huge potential for carbon sequestration. Herbal leys also provide a very rich mineral feed for livestock	LU Point	No drivers required - LU point interventions aren't assigned drivers
Leave autumn seedbeds rough	Leaving the autumn seedbed rough encourages surface water infiltration and reduces the risk of surface runoff, thereby reducing particulate P and associated sediment loss risks.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Maintain and enhance soil organic matter	Maintaining and enhancing soil organic matter levels helps to reduce the risks of surface runoff and erosion, enables improved water retention and the efficient use of soil and added nutrients. The long-term benefits of improved soil structure etc. should be effective in reducing particulate P and associated sediment losses.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Manage (avoid if possible) tramlines over winter. If run-off occurs break up any compaction.	Tramlines are generally established in autumn sown combinable crops at the time of drilling; they can result in the channelling of surface water and the development of rills and gullies on sloping erosion susceptible soils. Tramline management to improve water infiltration rates can help to reduce accelerated runoff and the loss of particulate P/sediment.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Monitor and amend soil pH status for grassland	The ideal soil pH for grass and clover is pH 6.0-6.5. pH levels above or below this cause expensive production losses. They affect nutrient availability which can lead to nutrients reaching the watercourse, affecting water quality and causing environmental damage. Liming is considered expensive and so rarely done. Instead, more nitrogen and other nutrients are applied to achieve the same output. This creates an inefficient system where too much fertiliser is applied and the vast majority is lost.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Plan bracken management to avoid soil erosion	Consider methods of bracken control that are appropriate for the location e.g. slope of site and pick those that will not risk erosion, especially if surface will be left exposed.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Plough in crop residues/green manure as a soil conditioner	This method can have many benefits including short- and long-term benefits for nitrogen management, prevention of nitrogen leaching, improving soil structure and increasing soil organic matter.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Retain (and enhance) over-winter stubble	It provides a winter food source for seed-eating birds, which feed on spilt grain and the seeds of broad-leaved weeds. It also provides spring and summer foraging and nesting habitat for other farmland birds and undisturbed habitat for other farmland wildlife including many pollinators and brown hare. If successful there will be: - naturally occurring arable plants providing seed and forage over the winter, spring and summer - farmland birds and brown hare foraging on the seed shed during harvest - farmland birds and pollinating insects using the winter stubble and spring fallow area - only low populations of blackgrass plants in the late spring that need targeted spraying Relevant cs codes: AB2, AB6	LU Point	No drivers required - LU point interventions aren't assigned drivers
Use correctly-inflated low ground pressure tyres on machinery to minimise compaction	Traffic from farm machinery is one of the main causes of compaction, which occurs whenever the ground pressure on the soil is greater than its ability to resist. Using correctly inflated, low ground pressure tyres will avoid compressing soil particles together too tightly which reduces the space between them, restricting the movement of water, nutrients, roots and earthworms as well as excluding the air vital for healthy soil micro-flora and fauna. Reducing the pressure works by extending the tyre contact patch and the number of lugs in contact with the ground, it reduces the depth to which pressure extends, improves traction and reduces both fuel consumption and working time.	LU Point	No drivers required - LU point interventions aren't assigned drivers

Avoid irrigating at high risk times	Irrigating at high risk times can increase risk of run-off and erosion and associated loss of soil and nutrients.	LU Point	No drivers required - LU point interventions aren't assigned drivers
Other - Custom intervention	Add in an explanation of the intervention delivered.		No drivers required - LU point interventions aren't assigned drivers

Field Parcel Intervention Features

Intervention	Description/Explanation	GIS Layer (layer name on the Interventions tab)	Reporting Driver (to ensure feeds through into reporting) *	Code used to represent this intervention in attribute table on AGOL - automatically populated by completing Survey123 Field Parcels Intervention form
Management of rough grazing for birds	This option is specifically for restoring or maintaining upland bird populations. The option brings about water level management and provides the appropriate grassland habitat and sward structure for feeding and nesting. Relevant CS code: UP2	Field Parcel Interventions	New non-permanent management in the farmed landscape or Restoration of semi-natural habitat	Mng_Rgrazing_birds
Management of permanent grassland with very low inputs	This option is where permanent grassland is managed with very low fertiliser inputs to provide higher value areas for wildlife. Relevant CS codes: GS2, GS5	Field Parcel Interventions	New non-permanent management in the farmed landscape or Restoration of semi-natural habitat	Mng_Pgrass_Vlow
Establishment of two year sown legume fallow	Established by the sowing of a seed mixture to provide pollen for insects and habitat for a wide range of farmland wildlife. Relevant CS code AB15	Field Parcel Interventions	New non-permanent management in the farmed landscape which improves biodiversity	2yr_SL_fallow

* Only drivers that directly feed into monthly reporting items are listed. However, it is important that other drivers are also selected where relevant, to aid additional categorisation, analysis and reporting of interventions.
There are three habitat/biodiversity drivers that, in the case of Polygon and Field Parcel Interventions, feed into monthly reporting items:
If the "**Creation of new permanent habitat**" driver is set, the area of a Polygon or Field Parcel Intervention will feed into the "Area of new habitat" monthly reporting item.
If the "**Restoration of semi-natural habitat**" driver is set, the area of a Polygon or Field Parcel Intervention will feed into the "Area of habitat restored" reporting item.
If the "**New non-permanent management in the farmed landscape which improves biodiversity**" driver is set, then the area of a Polygon or Field Parcel Intervention will feed into the "New non-permanent management in the farmed landscape which improves biodiversity" reporting item.
There is one additional driver that, in the case of Polygon and Field Parcel Interventions, will feed into a monthly reporting item:
If the "**NFM**" driver is set, then the area of a Polygon or Field Parcel Intervention will feed into the "Area of landscape managed for NFM" monthly reporting item.

Create or maintain uncropped cultivated margins	This intervention creates areas rich in annual plants which provide habitat for ground-nesting birds and insects and foraging sites for mammals within plots or strips that are cultivated but left undrilled/uncropped. Relevant CS code: AB11	Field Parcel Interventions	New non-permanent management in the farmed landscape which improves biodiversity	Uncrp_margins
Undersown spring cereals	This interventions provides the addition of a low growing grass/legume mix as an understorey to the cereal crop which will help to suppress weeds and build soil fertility and therefore reduce the need for agrochemical inputs. This intervention will also increase the diversity of habitat provided in the field and benefit farm wildlife. Relevant CS code: OP5	Field Parcel Interventions	New non-permanent management in the farmed landscape which improves biodiversity	Undersown_SprC
Nil fertiliser inputs	Implementation of this advice helps to reduce the risk of nitrate loss to ground and surface water by reducing nutrient inputs to zero. Relevant CS Code: SW14	Field Parcel Interventions	Could potentially be assigned 'New non-permanent management in the farmed landscape which improves biodiversity'	Nil_fert_inputs
Arable reversion to grassland with low fertiliser input	A dense grass sward in arable fields at risk of soil erosion or surface runoff will stabilise the soil, reduce nutrient losses, and buffer sensitive habitats, such as designated aquatic habitats. It will also reduce surface runoff, which may help to reduce the risk of flooding. Relevant cs code: SW7	Field Parcel Interventions	Creation of new permanent habitat or New non-permanent management in the farmed landscape which improves biodiversity	Arable_reversn
Cultivate land for crops in spring rather than autumn	Autumn cultivation of land stimulates the mineralisation of N from organic matter reserves at a time when there is little N uptake by the crop, which will increase the potential for over-winter NO3 leaching losses. By cultivating in spring, there will be less opportunity for mineralised N to be leached and the N will be available for uptake by the established spring crops, and there will be less risk of particulate P losses in surface runoff.	Field Parcel Interventions	New non-permanent management in the farmed landscape which improves biodiversity	Spring_crops

Enhanced management of maize crops	It reduces the risk of soil erosion and surface runoff in fields where maize is grown. It will slow runoff water before it builds to a damaging flow, and remove sediment, organic material, nutrients and chemicals carried in the water. CS code: SW5	Field Parcel Interventions	New non-permanent management in the farmed landscape which improves biodiversity	Enh_mng_maize
Establish cover crops in the autumn	Without a cover crop, NO_3 can be lost through over-winter leaching and particulate P can be lost through sediment transport in surface runoff. To be effective in reducing NO_3 leaching, the crop needs to take up N before the onset of winter drainage, but thereafter the date of destruction is less critical. To be effective in reducing particulate P and sediment losses the crop does not have to be alive (i.e. straw and crop residues can be effective), but the soil must be protected throughout the period when surface runoff can occur.	Field Parcel Interventions	New non-permanent management in the farmed landscape which improves biodiversity	Aut_cover_crops
Soil aeration	Soil aeration increases the porosity and permeability of a soil to allow more air to reach roots, improving root development and alleviating s compaction. With this method infiltration and drainage will be improved, reducing surface run off volumes and slurry and fertilizer runoff.	Field Parcel Interventions	NFM	Soil_aeration
Reducing stocking density and fertiliser inputs on intensive grassland adjacent to a watercourse	Reducing stocking density and fertiliser inputs on improved grassland will help reduce soil compaction, surface run-off and risk of diffuse pollution to the watercourse. Reducing surface runoff may help to reduce the risk of flooding. The option may also reduce the risk of nitrate loss to ground and surface water if it is used with SW14 - Nil fertiliser supplement. Relevant CS code: SW8	Field Parcel Interventions	Please select relevant drivers.	IntGrass_watercrse

Management of invasive non-native species (INNS)	Active management and eradication of invasive non-native species such as: - Himalayan balsam - Japanese knotweed - Floating pennywort and other invasive aquatic plants Active management will maintain or restore wildlife value or protect archaeological features. If successful there should be a reduction in cover and density of non-native invasive species. Native plants and animals will re-establish the area cleared, returning a more natural balance to the habitat.	Field Parcel Interventions	Restoration of semi-natural habitat	Mng_INNS
Other - Custom intervention	Add in an explanation of the intervention delivered.		Please select relevant drivers.	Other

Financing One Coast: A review of possible finance mechanisms for the One Coast Project

010 SWEEP

1. Introduction

The One Coast project is a landscape scale conservation initiative which aims to create a continuous nature rich and accessible coastal corridor in the SW, for the benefit of nature and people. The coastal corridor is defined as the continual strip of land stretching from Mean High Water 1km inland around the entire SW Coast. The landscape scale ambitions of the One Coast project require careful consideration of possible sources of finance, including consideration of new and innovative finance mechanisms and the establishment of a One Coast investment plan.

This review outlines a range of possible finance mechanisms that could be used for the One Coast project, alongside traditional grant and philanthropic sources of finance. It represents the first step towards the development of a strategic plan and investment plan for the One Coast project. The review is restricted to the area of the coastal corridor which lies within Cornwall and is informed by the accompanying One Coast Evidence Base (2019). A range of possible finance mechanisms relevant to the One Coast project area are briefly described, accompanied by a review of their relevance for the One Coast project. The aim of this review is to present a range of possible options for consideration by the National Trust and the RSPB.

2. Finance Mechanisms

A finance mechanism simply refers to a method or source through which finance is made available. In the UK, nature conservation initiatives have traditionally been financed through public finance (budget allocations, grants or payments to land owners) or philanthropic donations. Since 2010 there has been a growing focus on new and innovative sources of private finance for nature conservation, driven by a decrease in the availability of public finance (Somper 2011[1]) and a realisation of the need to upscale conservation initiatives to meet national and international targets to halt biodiversity decline (Parker et al. 2012[2]). Alongside traditional grant programmes, there are now a diversity of mechanisms which can be used to generate finance for nature conservation, from Payments for Ecosystem Services to Visitor Taxes, Biodiversity Net Gain and Green Bonds (Parker et al. 2012). Many of these emerging finance mechanisms focus on tapping into private finance and employ market-based approaches.

The rise of private and market-based approaches to conservation finance has sought to expand the pool of potential investors in nature conservation, to include corporates, impact investors, institutional investors and retail investors. However, implementing emerging market-based finance mechanisms is a new challenge for the conservation sector. Although private investment can sit alongside traditional forms of funding (e.g. government or local authority budget allocations, philanthropic grants, corporate and private donations etc), it often requires the conservation sector to not only generate positive outcomes for nature but also a reliable long-term return on investment. Generating reliable revenue streams from natural capital is challenging as many parts of society already receive benefits [ecosystem goods and services] free of charge. Private investment in natural capital is, therefore, often based on identifying opportunities where revenues or cost saving could be delivered through improving the natural environment.

3. Linking the One Coast Evidence Base and Possible Financial Mechanisms

The One Coast Evidence Base highlights a number of features of the coastal corridor that could help shape the choice of financial mechanisms used for the One Coast project. Features identified in the One Coast Evidence Base with a connection to a possible finance mechanism are briefly described below, prior to more detailed analysis in Section 4.

One of the most immediately striking aspects of Cornwall's coastal corridor is its high number of usual residents. An estimated 37% of Cornwall's total population is thought to reside in the coastal corridor, resulting in a population density more than twice that of the rest of Cornwall. The high number of usual residents emphasises the desirability of the coastal corridor as a place to live and work. The large population also means that there is potentially a large number of people with a high level of place attachment or sense of place linked to living and working in the coastal corridor. Place attachment could be a key driver for the development of community-based action focused on enhancing the coastal corridor in which so many people already live and work. Community based actions which could be facilitated by the project partners include the potential set up and development of a network of community land purchase schemes along the coastal corridor, community action funds and even SEED funds for community trusts. Notably, the population of the coastal corridor is potentially wealthier than much of the rest of Cornwall, with a higher proportion of usual residents

[1] Somper, J., 2011. Funding trends – the implications for future nature conservation. ECOS Spring, pp.32, 1, 34-42. Available at: https://www.banc.org.uk/ecos-32-1-spring-2011-funding-trends-the-implications-for-future-nature-conservation-jonathan-somper/ [Accessed June 22, 2019].

[2] Parker, C. et al., 2012. The Little Biodiversity Finance Book: a guide to proactive investment in natural capital (PINC) 3rd ed., Oxford: Global Canopy Programme. Available at: http://globalcanopy.org/sites/default/files/documents/resources/LittleBiodiversityFinanceBook_3rd edition.pdf.

in professional, technical, senior and managerial roles, in the coastal corridor, and average house prices some 27% higher than the rest of Cornwall. The presence of high net worth individuals could be a key source of private donations for the coastal corridor and set up or development capital for community-based action. Furthermore, there is a much higher proportion of residents over 65 and retirees living in the coast corridor compared to the rest of Cornwall. Choosing to retire to the coastal corridor is another indication of the high potential level of place attachment of residents, and also indicates a high potential for legacies linked to enhancing and improving the coastal corridor.

Not only are there a higher number of residents in the coastal corridor but there is also increasingly an ageing population, with predictions that by 2030 some 31% of the population of Cornwall will be over 65. An ageing population is likely to place a much higher demand on services such as health and care provision and is likely to drive a shift towards a more service and care driven economy. There is an ever-growing evidence base supporting the beneficial health effects of spending time in natural environments. Coastal environments are no exception, Wheeler et al. (2012[3]) found that populations living near the coast in England are healthier than those inland (Wheeler et al. 2012) and longitudinal data suggest that individuals are healthier during periods when they live closer to the coast (White et al. 2013[4]). The health benefits of coastal environments are thought particularly to be linked to increased opportunities for recreation (Wheeler et al 2012, White et al. 2013). Using the ORVal tool[5], the One Coast Evidence Base indicates that the Coastal Corridor is already likely to be a key location for recreation, with 49% of total predicted recreational visits by adult residents to greenspaces in Cornwall taking place in the coastal corridor (18.64 million), with an associated welfare benefit to residents of £74 million [51% of the total value of welfare benefits to residents from recreational visits to greenspaces in Cornwall] (Day and Smith 2018[6]). Both the prospective health and care demands of an increasingly ageing population and the recreational value of the coastal corridor point to the potential use of health or recreation-based schemes to fund enhancements of the coastal corridor close to urban areas, also known as social prescribing. Social prescribing has already been established in some areas of Cornwall through the Dose of Nature project[7], and has the potential to be further developed through the One Coast project or targeted to project partner areas in the coastal corridor. Notably, the health benefits of the coastal environment are thought to be particularly significant for reducing health inequalities faced by deprived communities, and therefore any further development of a social prescribing system could be targeted at the neighbourhoods suffering from the highest levels of deprivation in the coastal corridor (see One Coast Evidence Base, Section 2.10).

The coastal corridor is a key area for real estate development and construction. The Cornwall Site Allocations Development Plan Document (Allocations DPD) identifies where new housing and employment uses are planned across Cornwall. Based on Cornwall Council's Site Allocation Development Plan, some 36% of all 'allocation sites' (by area) lie within or intersect the coastal corridor. Based on estimated dwelling numbers for housing-based allocations, 50% of allocated dwellings will be in sites that intersect or lie within the coastal corridor. The concentration of future development within or close to the coastal corridor could place further pressure on its natural capital assets, with a particular concern around impacts on the mobility of coastal margin habitats and the loss of rare semi-natural grasslands. However, development on more commonplace habitats could be an opportunity to help finance the One Coast Project through the delivery of off-site biodiversity net gain requirements. The preference for the delivery of biodiversity net gain will always be on-site, however, there are some cases where developments will not be able to deliver biodiversity net gain within their development footprints despite adhering to the mitigation hierarchy. Where off-site compensation is deemed appropriate by the Local Planning Authority it can take place either through bespoke offsetting, where developers engage a third party to deliver offsite compensation, or via an in-lieu fees approach, where a defined contribution is collected and then distributed to delivery partners to undertake an offset on the behalf of the Council/developer. Cornwall Council is currently developing a local net gain framework, which is proposed for rollout in September 2019 and is likely to be mandated by January 2020 for all major developments. Under the Cornwall Net Gain framework, there is likely to be a strong preference for compensation sites that are close to the development or impact site. This is likely to be defined as within the same sub-catchment as the development or impact site. Given the concentration of allocated developments within the coastal corridor, there is a clear argument for also locating off-site compensation sites, or offsets, within the coastal corridor. Net gain frameworks could potentially provide both capital and 30 years of maintenance and management costs for habitat creation but will require proactive identification of viable and cost-effective delivery sites, ideally close to potential impact sites.

Some 44% of Cornwall's enterprises are estimated to be located in the coastal corridor, including 25 businesses with over 250 employees. Many corporations are increasingly conscious of environmental and social issues, particularly customer or citizen facing

[3] Wheeler et al (2012) Does living by the coast improve health and wellbeing? Health Place, 18(5). 1198-1201. doi: 10.1016/j.healthplace.2012.06.015.
[4] White et al (2013). Coastal proximity, health and well-being: results from a longitudinal panel survey. Health Place; 23:97–103.
[5] https://www.exeter.ac.uk/leep/research/orval/
[6] Day, and Smith (2018). Outdoor Recreation Valuation (ORVal) User Guide: Version 2.0, Land, Environment, Economics and Policy (LEEP) Institute, Business School, University of Exeter.
[7] https://www.adoseofnature.net/

corporates with an interest in cultivating an image of Corporate Social Responsibility (CSR) and environmental concern. A corporation's environmental or sustainability strategy can include a commitment to offset carbon emissions or to invest locally in environmental or social projects such as One Coast. There are a number of initiatives to encourage environmentally friendly economic growth nationally, while locally the TEVI project, an EU funded collaboration between Cornwall Council, the Cornwall Development Company, Cornwall Wildlife Trust and the University of Exeter, is helping a range of enterprises to achieve green growth. Some 40% of the 100+ businesses engaged with the TEVI project are located in the coastal corridor. Following models such as the RSPB Energy for Nature Scheme and the Woodland Trust's Smithills Estate, Bolton, the TEVI network could be a key source of expertise and business investment to enable the development of Natural Capital Based Ventures to help finance conservation across the coastal corridor. In addition, some enterprises have clear dependencies or impacts on natural capital and are more likely to be willing to engage, participate and invest in environmental projects in the coastal corridor to generate environmental improvements and demonstrate environmental credentials. Sectors with considerable natural capital dependencies include agriculture, aquaculture, fisheries, forest products, utilities, and mining. There is an increasing number of tools available which highlight the dependencies of different industries or sectors on natural capital (e.g. ENCORE[8]). Furthermore, large agri-food industries and the tourism industry rely on the green and pleasant image of Cornwall to brand and market their products. One route to investment could also be to target companies which brand products linked to the aesthetic and cultural value of Cornwall's natural or coastal environment, and could have a much stronger business case for investing in the coastal corridor.

The tourism industry is a main driver of the Cornish economy, and it is also a sector which is *"inextricably linked to Cornwall's unique environment, including its coastline and cultural heritage"* (Cornwall Council 2012[9]). Some 53% of tourist sites lie within or intersect the coastal corridor. An estimated 5.34 million day/staying visits per year are made to coastal areas in Cornwall (28% of total) (SWRC 2016[10], 2018[11]). Conservative estimates suggest that the coastal corridor, excluding beaches and coastal resorts, receive an estimated 2.26 visitors per year (*SWRC 2016[12])*, however, this number could be as high as 14.88 million visitors per year (SWRC 2016). Coastal areas are estimated to be linked to a tourist spend of around £666 million per year, and the coastal corridor an estimated £178 million per year, equating to on average 10% of the total visitor spend in Cornwall and 26% of coastal spend (SWRC 2016, 2018[13]). Both the volume of visitor numbers and the visitor spend highlight the potential for the use of a county-wide visitor tax or voluntary visitor giving scheme to help fund the One Coast project. The Council is already investigating the introduction of a visitor tax at the county scale, and a VP scheme linked to the coastal corridor could be developed in conjunction with the South West Coast Path Association.

Enclosed grasslands and farmlands dominate the coastal corridor (64%). This dominance means that any effort to create a nature-rich and accessible coastal corridor needs to consider approaches for enhancing agricultural land for biodiversity and multiple ecosystem service provision. An estimated 372 farmers (8.2% of the total estimated farms) have land intersecting or within the coastal corridor, currently supported by around £9,723,000 per year basic payment schemes. Agri-Environment agreements currently cover some 13,916 ha of the coastal corridor, with a total annual value to agreement holders of £1.597 million (an average of £115/per ha). Enclosed grasslands, including arable and horticultural areas and improved grassland, have considerable potential to deliver ecosystem services. The highest potential for the delivery of ecosystem services is likely to be reduced soil erosion by wind and water, improvements in bathing water quality, carbon storage and sequestration, biodiversity and pollination services, with more limited areas with potential to aid flood mitigation and freshwater quality improvements. In partnership with the Council, the tourism industry, the Environment Agency and SW water utilities, targeted wetland, coastal margins or woodland habitat creation could be used to try to improve bathing water quality, reduce flood risk and sequester carbon. The set-up of specific Payments for Ecosystem Services schemes linked to soil erosion, bathing water quality, or carbon storage and sequestration could be a key pathway to encourage environmental improvement in the One Coast project areas. Alternatively, enhancing species richness could be encouraged through the piloting of a dedicated result based agricultural scheme targeted to provide bonus payments for coastal corridor farmers where they provide nature rich environments close to coastal margins or undertake land sparing close to the coastal path. One final option is the development of a certification scheme focused specifically on farmers in the One Coast area, much like for the RSPCA welfare standard for salmon farmers, the certification scheme could provide added recognition for coastal farmers delivering environmental enhancements. A certification approach could be of particular interest for corporates in the agri-food

[8] https://www.investmentweek.co.uk/investment-week/news/3067084/encore-new-tool-to-highlight-natural-capital-risks-for-investors; https://encore.naturalcapital.finance/en/data-and-methodology/methodology
[9] Cornwall Council (2012) Economy and Culture Strategy Evidence Base - https://www.cornwall.gov.uk/media/3624007/Economy-and-Culture-Strategy-Evidence-Base.pdf
[10] Please note that these data exclude regular non-tourism related residential use such as dog walking.
[11] SWRC (2018) Cornwall Visitor Survey 2018/19 Quarterly update, Produced on behalf of Visit Cornwall.
[12] SWRC (2016) SW Coast Path Monitoring and Evaluation Framework, Year 5 (2015) Key Findings, Produced on behalf of the SW Coast Path Team.
[13] Observatory of the Cornwall Marine Leisure Industry Draft in preparation 2010. Nautisme Espace Atlantique Project, Cornwall Development Company.

industry who specifically market their products based on the aesthetic and environmentally friendly image of Cornwall (e.g. Davidstow Cheddar[14]).

Finally, woodlands cover some 11% of the coastal corridor. Woodlands contribute to the corridor's high potential for above ground carbon storage, potential to provide water quality and quantity mitigation, provide opportunities for recreation, air quality amelioration and noise mitigation. There are a variety of existing approaches that could help fund further woodland creation across the coastal corridor. One route could be to use the Woodland Carbon Fund or Voluntary Carbon Offsets to provide an additional stream of finance and cover set up and capital costs of woodland creation; this finance could potentially be bundled with net gain finance to provide more attractive prospects for land owners. Transport and logistics firms linked to Cornwall with high carbon footprints could be targeted for voluntary carbon offsets, as well as large-scale enterprises. However further investigation is required to understand current levels of interest in investing in local voluntary woodland carbon offsets and the potential returns on investment. Notably, woodland creation is high on Cornwall Council's agenda, as a response to the declaration of a current climate emergency and linked to initiatives such as the Forest for Cornwall (*Cornwall Council pers comm*). The development of new woodlands for biodiversity and profit could be undertaken in partnership with established bodies in the sector, such as Forest Carbon, the Forestry Commission and the Woodland Trust.

[14] https://www.davidstowcheddar.co.uk/

4. Finance Mechanisms

4.01 Transient Visitor Levy and Visitor Giving Schemes

Transient Visitor Levy

More and more countries, including the majority of European member states, have some kind of tourist tax or a Transient Visitor Levy (TVL) linked to combating the problems caused by over-tourism. A range of taxes can be included under the label tourist taxes, including specific corporate income tax and VAT. A Transient Visitor Levy (TVL) is a specific occupancy-based tax levied on short-term stays and typically charged per person per night. TVLs generally consist of a small night-based fee of between £1 to £5 across Europe. For example, the Balearics Sustainable Tourism Tax was introduced in 2016 to aid environmental and tourist improvements, is collected when tourists arrive at their accommodation, and can range from 1-4 euros per night depending on the quality of accommodation, peak or off-peak season and length of stay. In general, TVLs are designed to offset the impact of tourists on local infrastructure and services, the tax income is most often used for funding infrastructure and essential services affected by tourism, including road maintenance, policing, facilities and also to support the future growth of tourism. TVLs are generally collected when tourists arrive or leave their accommodation. As tax rates can be varied based on the standard of accommodation (star rating), location, visitor age and season, there is significant capacity for Local Authority discretion in the application of a TVL.

In the UK, Scotland is currently leading the way in the introduction of TVLs. From 2021 Scottish Councils will be able to levy a tourist tax. The proposals for Edinburgh are for a £2 a night occupancy tax, which received strong support from local residents but more negative feedback, as to be expected, from the tourism industry. At present Local Authorities (LAs) in England are not allowed to raise money through TVLs. However, over recent years a number of city councils and LAs in England have pushed for new powers to be able to introduce tourist taxes to offset funding cuts, including Bath, North East Somerset Council, Liverpool, Birmingham and York. In particular, Bath and North East Somerset Council have made formal lobby to the government for the power to charge visitors a tourist tax, specifically to introduce a £1 per night levy on hotels and holiday lets. Birmingham City Council has proposed the introduction of a levy on visitors to pay for the 2022 Commonwealth Games, while Liverpool city councillors have pushed for a voluntary tourist tax for cultural events.

In Cornwall, the idea of introducing a TVL was raised in early 2019 by Cornwall Council and is currently being investigated by the Council in coordination with other LAs. Cornwall Council estimates that an extra £25 million could be raised through the introduction of a £1 a night tax on overnight staying guests. The council proposals currently suggest that tax revenue could be used to finance infrastructure maintenance and improve the tourist experience. The introduction of the TVL is outlined as a potential mechanism to perform infrastructure maintenance, as the number of visitors in the county increases. The aim of the fund would be to also improve the tourist experience.

Opportunities

The One Coast Evidence Base highlights the significance of the coastal corridor for the tourism industry in Cornwall. With an estimated, 2.26 million visitors per year *(*with higher estimates reaching 14 million), responsible for around £178 million of visitor spend (SWRC 2016; 2018). The significance of the coastal corridor for the Cornish tourism industry and the volume of visitors means that consideration must be given to the potential for the tourism sector to help finance the One Coast project, either via a Transient Visitor Levy (tourist tax) and/or a Voluntary Visitor Giving Scheme. Tourist taxes are a response to the pressure high levels of tourism places on local infrastructure and services. The One Coast Evidence Base clearly indicated that the tourism industry derives significant value from the coastal corridor and in turn, the natural capital assets in the coastal corridor are disproportionately under pressure in terms of recreational sites and visits compared to the rest of Cornwall (One Coast Evidence Base 3.03.01). There is a strong argument that any investments made in improving physical infrastructure could also be extended to apply to improving the natural capital assets and resilience of the coastal corridor. Investing in restoring the coastal corridor would be a chance for both visitors and the tourism industry to support a key source of their enjoyment (visitors) and income (tourist industry). Investing in the coastal corridor would also be a positive action for the Council as this would support the future growth potential and resilience of the Cornish Tourism industry and could encourage increased visitor numbers. The TVL would reflect the true cost of tourism in terms of recreational pressure on the coastal corridor and the need for the tourism industry to invest for its future.

The One Coast partner organisations could take a number of actions to encourage the development of a local TVL:

1. Partner with large tourist organisations such as Airbnb, booking.com etc, to trial the introduction of a TVL directly linked to investing in the coastal corridor.
2. Introduce a specific TVL for National Trust holiday accommodation.
3. Support and highlight the need for a TVL to Cornwall Council, and specifically emphasise the need to allocate revenue from the tax towards natural capital investment in the coastal corridor as a means to invest in the future development of the tourism industry.

Issues or Challenges

In general, research and consultation on the introduction of TVLs in the UK has received considerable support from local residents but more negative reaction from the tourist industry. There are also a number of common concerns surrounding the introduction of a TVL. In particular, there are concerns that collection could prove difficult and that the tax would be off-putting to tourists. The tourist lobby, for example, the Cornwall Federation of Small Businesses, are not likely to support the introduction of a TVL. There are also concerns regarding how the tax revenue will be reinvested in the area, and the potential losses through administration expenses and enforcement outweighing the benefits.

Voluntary Visitor Payback

In comparison to an involuntary TVL, Visitor Payback (VP) involves the voluntary process of visitors choosing to give money (or other help) to assist in the conservation or management of places they visit. VP is an entirely voluntary payment that directly connects the visitor to specific conservation projects, thereby heightening their own tourist experience. Under a VP system, visitors are paying voluntarily for the maintenance and enhancement of particular ecosystem services which they value. A variety of techniques can be used in the pursuit of VP, including donations, opt out/opt in levies, merchandising, membership, participation, fundraising, sponsorship and loyalty cards. VP schemes are increasingly being promoted as additional sources of finance for landscape scale conservation schemes and included by Defra under the label of Payments for Ecosystem Services.

A review by Reed et al. (2013) identified twenty-two active VP schemes in the UK, with an average amount donated of £3.45. In general, Reed et al. (2013) found that the main benefits of VP were increased awareness, education and promotion of the conservation project, but warned that they may not always generate significant revenue and can often have high administration costs. The income potential of VP schemes should therefore not be seen as the be all and end all, as VP often do not provide a means of delivering substantive revenue. Caution should be taken in introducing a VP to ensure that there is not a perception that the countryside is becoming over commercialised. Balancing administration costs and donation level is also key. There can also be some inherent negativity around the use of the phrase visitor ‘payback’, as this implies visitors cause damage and this requires compensation. More successful schemes have focused on giving and investment in an area to return to. VP schemes also require a strong partnership between the tourism industry, conservation organisations and visitors, and therefore partnership with Visit Cornwall may be crucial.

In relation to landscape scale restoration projects, such as the One Coast project, research demonstrates that VP is generally most successful when:

- Visitors can contribute towards specific projects that deliver tangible, measurable benefits to society.
- It enables visitors to give towards the preservation of a specific targeted area they visit - Prioritise local projects and seek funding from visitors only when they visit the area local to the project.
- Where scheme offers multiple investment options targeted towards different visitor profiles, relevant to their interests.
- Where schemes offer a range of different payment methods e.g. smart phone apps, donation boxes or opt in levies.
- Visitors can donate quickly and easily; this characteristic should, therefore, be paramount in the design of the payment method of VP.
- There is good marketing, particularly online and social media-based marketing.
- There is a range of projects to contribute to.
- Positive language focuses on investment.
- There are minimal running costs.

- There is immediate feedback on the effect of individual donations, demonstrating the benefits and making it clear that other visitors are also donating.

Options for payment methods
• Smart phone apps • Donation boxes on-site • Payment by text • Opt-in levies on accommodation/ voluntary levies on services e.g. car parking • Merchandising with a proportion of the income being given to a conservation project

Box 1. Options for VP payment mechanisms

Case studies

Nurture Lakeland

The Nurture Lakeland[15] pilot PES project, started in 2010, developed a VP scheme for conservation and tourism organisation in the Lake District National Park. Nurture Lakeland represents over 1,200 individual businesses, from small guest houses to large hotels, holiday cottages, conservation bodies and other tourism related businesses. Visitors are given the option to invest in a range of specific ecosystem services specifically linked to certain walking and cycling routes in a smart phone app or on the website, such as peatland restoration or the creation of a bee/butterfly corridor; there are also options to offset carbon emissions per mile travelled by car. Since 2010, VP has raised over £2 million for conservation projects. The scheme made use of existing apps such as the Nurture Lakeland sustainable transport app. The findings of the Nuture Lakeland VP pilot project were included in the development of a best practice guide and a VP toolkit developed by Visit England[16].

Caring for the Cotswolds, Cotswolds AONB

Caring for the Cotswolds[17] is a VP scheme whereby businesses ask visitors to voluntarily support local conservation projects by donating small amounts of money via their bill or fees, and these funds are then collected for local environmental projects. Caring for the Cotswolds is a joint initiative with the tourism industry and based on the premise that visitors may wish to contribute towards the conservation of the place they have come to visit. The revenue is then distributed through a grant scheme, with grant levels between £500 to £2500.

Opportunities

VP schemes are well suited to the One Coast project as VP schemes are thought to be most successful when visitors can contribute towards a specific project that is delivering tangible benefits to an area they visited. VP schemes are also a resource mobilisation technique that both of the One Coast project partners are already well accustomed to and are well suited to upscaling using in-house expertise. VP also represents an awareness raising opportunity to help highlight the need for finance for the One Coast project. Furthermore, VP avoids the perception of a 'bed or visitor tax' and is more likely to be accepted and embraced by the tourism industry. However, at present VP schemes within the National Trust are generally locally tailored, individually focused and small scale generating minimal scale finance (*NT pers comm*). The VP schemes which have developed have focused on developing individual partnerships with targeted hotels or local businesses. To upscale VP for the One Coast project, there is a clear need to achieve signup of a large number of businesses, as set out in the Caring for the Cotswolds and Nurture Lakeland case studies. The development of the scheme may be reliant on one-off grant aid to kick start the project and a percentage of collected finance reinvested to support long term viability of the scheme. Key partners for the development of VP include Visit Cornwall, the SW Coastal Path Association and the Cornwall AONB.

[15] http://www.nurturelakeland.co.uk/
[16] https://www.visitengland.com/sites/default/files/downloads/visitor_giving_helpsheets.pdf
[17] https://www.cotswoldsaonb.org.uk/looking-after/caring-for-the-cotswolds/

Issues

Successful VP schemes indicate the need to show specific links and benefits, targeting donations clearly towards specific projects and demonstrating how donations will lead to measurable ecosystem services benefits which could lead to the restricted use of funds. The amount of finance generated through VP is influenced by wider economic circumstances and trends, with visitors less inclined to donate when the economy is poor. The individual amount donated through VP tends to be low and can suffer from high administration costs. Set up of a coastal corridor wide scheme would require a considerable initial investment in start-up and marketing.

Linked resources and guidance

Reed et al. (2013) Visitor Giving Payment for Ecosystem Service Pilot Final Report, Defra, London.
http://randd.defra.gov.uk/Document.aspx?Document=11917_VGSPESPilotFinalReportFeb14.pdf

Visit England (2012) Visitor payback toolkit, Available at:
https://www.visitengland.com/sites/default/files/downloads/visitor_giving_helpsheets.pdf

4.02 Community Land Trusts and Ownership

Community Land Purchase (CLP) and Community Land Trusts (CLTs) are associated with the purchase, or leasing, and management of land or assets by a community. The word community can be taken to refer to a group linked by place or by common aims or interests, or a common background. The land or assets purchased or leased by communities can include, village shops, pubs or greens, sports fields, sites for self-build housing, agricultural land or woodlands. CLP is undertaken for a wide range of purposes but, in general, it takes place where a community comes together to invest in a site for a common purpose. In many cases, CLPs have been undertaken in order to enable and empower communities in decision-making on development, natural resource use and ecosystem service provision. CLPs can also be driven specifically by nature conservation objectives. The purchase of woodland, or land to restore to woodland, has often been the focus of nature-based CLPs, however, it has also taken place to facilitate community supported agriculture, aiming to catalyse rural development (Mackenzie 2012[18]).

Community land ownership and land purchase are much less embedded in UK culture than in many other countries in Europe. In France, there are some 11,000 forest communes, while in Germany rural communities have owned forest for centuries. However, since the 1990s community ownership had become much more popular, particularly as a result of the land reform act in Scotland, the National Forest Land Scheme, the 2010 Localism Bill[19], and initiatives such as the Community Woodland Association. Scotland pioneered community ownership in the 1990s on Assynt, Knotdart and Eigg, driven by issues with housing quality and land tenure. The Scottish Government has a target to achieve one million acres of land in community ownership by 2020, driven by a focus on democratising decision making on land and natural asset use at the local level. Community ownership is also thought to have the added benefit of promoting community cohesion and improving social capital through enhanced skills and experience. For community members involved it can also build community confidence and sense of worth. Notably, research has found that CLP can have the added benefits of catalysing other local economic and community activities (Mackenzie 2012).

UK community land trust and ownership organisations operate under a wide variety of tenure and ownership arrangements, finance structures and governance, from traditional models such as charities and trusts to more social and environmental investment businesses. A key aspect is to enable the group to have the ability to enter into legal contracts, to become an incorporated organisation. CLP groups operate under a diversity of objectives with varying degrees of participation by community members. Ensuring clarity of purpose is critical in forming CLP groups; technical challenges also include ensuring individuals are protected from liability. Historically, CLPs have largely been set up as charities or trusts, however, more recently research projects have looked at new ways for social enterprises to attract funding through equity or bonds where community investment makes a financial, social or environmental return on investments via interest or dividends. Community investment is generally defined as the sale of more than £10k in shares or bonds to communities of at least 20 people, i.e. they are financial ventures serving a community purpose. However, these sorts of finance investments need to generate a sufficiently attractive financial, social or environmental return on investment, e.g. community facilities, local carbon initiatives, woodland products can all help raise capital returns. The Phone Co-op is a classic example, it harnesses the combined financial powers of whole communities with a large amount of capital being raised in relatively small amounts from each member. In 2007 it had a membership of 6,700 who had collectively invested £1.6 million, with an average investment of £237 but a median investment of only £30.

Case studies

There are a wide range of CLP examples across the UK and internationally:

The Isle of Eigg Heritage Trust, Scotland	A CLP project to deliver landscape scale conservation through sustainable land management through community action for habitat management and recreation.
Community Commons, Herefordshire, England	A five-year project (2004-2009) led by the Herefordshire Wildlife Trust to improve the condition of twelve commons (1000ha) for wildlife and local people. Improvements were made through introducing more effective management regimes and using local people and community groups to secure long term sustainable management, recreational and education opportunities. Funded by a combination of Heritage Lottery Funds and Agri-Environment Schemes.
Heaton Woods Trust,	Heaton Woods Trust formed 30 years ago when residents bought land in danger of being

[18] Mackenze, F.D., (2012) Places of Possibility Property, Nature and Community Land Ownership, Wiley Blackwell.
[19] The Localism Bill generated opportunities for community right to buy.

Bradford, England	developed and planted it with trees. It was established as a Registered Charity in 1978 as an offshoot of Heaton Township Association. Its main aim is to preserve and replant Heaton Woods, the majority of which is now in the ownership of either Bradford Council or The Trust. The group is funded through sales of wood chippings and logs, grants and membership.
Whistlewood Common, Melbourne, Derbyshire	Community share offered to enable the purchase of 10 acres of a former market garden to create Whistlewood Common is now used for community food production.
Stroud Woods, Gloucestershire	Cooperative set up as an industrial and provident society with the aims to realise the environmental, biological, landscape, economic, social, cultural, educational and recreational value of woodland ecosystems in and around Stroud as a resource for a sustainable community.
Wilshire Community Land Trust, Wiltshire	Wiltshire Community Land Trust offers advice on establishing local community land trusts, it is a volunteer led organisation that owns and manages assets for the benefits of a defined community.
Mull of Galloway Trust, Scotland	A community takeover developed as the best way to balance Mull's tourism potential with the need for environmental protection - and the Mull of Galloway Trust was set up to achieve it.
Loch Druidibeg, South Uist, Scotland	Purchase of 1100ha of land at Loch Druidibeg, South Uist, by a local group 'Stora Uibhist', working in partnership with RSPB Scotland after taking ownership of the land from Scottish Natural Heritage. The group aims to carry out habitat, goose and deer management, improve drainage and water quality.
The landcare community group, Australia	A network of local community groups working to protect natural resources and the environment. More than 4000 groups are working across Australia on sustainable management of farmland, improving river systems and waterways and coastal management, tree planting and restoring wildlife. Groups are formed by people with a common concern, through bottom up community actions as part of a wider network. Groups often work on public areas such as roadsides. Landcare group members provide the majority of funds.

Opportunities

Some 37% of Cornwall's population live and work in the coastal corridor, however many Cornish residents may not be able to individually own coastal land any larger than their back garden but could be interested in investing in shares of coastal land. For the One Coast project, developing a network of CLP groups along the coastal corridor could offer an additional route for land purchase for project partners, and provide committed and long-term volunteer groups to support the restoration and on-going management of natural capital assets. The project partners could take on a leadership role in the development of a Cornwall-wide network of CLP groups, working in partnership and providing expert knowledge and support where necessary for CLP groups. Initial set up work would be needed to catalyse and gauge the potential level of interest including an initial survey of existing community groups and residents. Awareness raising on the importance of the coastal corridor and the potential for CLP would be a critical first step. Once the network of CLP groups was established, possibly linked to different sections of the coastal corridor, the focus could then shift towards capacity building, particularly the provision of technical support and education on the development of CLPS, e.g. technical aspects of acquisition, liability etc, through clear and high-quality information and advice tailored to local needs. Notably, environmentally focused CLP have included North Harris and Knoydart, which have raised funds to employ rangers, engage in environmental education, and provide opportunities for locals and visitors to experience the local environment, and explore eco-tourism opportunities. An essential aspect allowing CLPs to take on/ mainstream environmental objectives is the perspective of the environment as a key part of the asset base for a region.

Issues

There are a number of issues facing CLP and management initiatives. Existing literature most often emphasises the economic barriers to CLP due to limited income streams, particularly in the face of government funding cuts. Lack of community cohesion can also be a key barrier. Communities engaging in, or those which have completed, buyouts are not necessarily cohesive and can face internal conflicts around buyouts, different values or objectives, and externally between community groups and environmental oriented partners. Other key issues include a lack of technical expertise and capacity. Furthermore, there are issues with trying to push grass roots CLP from the top down, placing communities under pressure to take on assets that they may view as more of a liability. Reliance on community-based finance means that it may be vulnerable to future changes in the financial and economic landscape.

Resources

The Woodland Trust (2011) Community ownership for woodland management and creation – Community Woodland Ownership, Research Report, Available at: https://www.woodlandtrust.org.uk/mediafile/100263178/rr-wt-71014-community-ownership-for-woodland-management-and-creation-.pdf?cb=f6144e3b40534c458e896052a12a9132

MacLeod, C., (2017) The future of Community Land Ownership in Scotland, A Discussion Paper, Highlands and Islands Enterprise, Online report, Available At: http://www.calummacleod.info/couchuploads/file/the-futureofcommunitylandownershipinscotlandadiscussionpaperfinal-2.pdf.

Community Land Advice (2019) Community Land Advisory Service, Webpage, Available at: https://en.communitylandadvice.org.uk/en/buying-land

Forestry Commission (2013) A framework for sharing experiences of community woodland groups, Available at: https://www.forestresearch.gov.uk/documents/190/FCRN015_RZLgaTl.pdf

4.03 Green Prescriptions

Green prescriptions, also called nature-on referrals, are therapeutic or treatment-based interventions recommended by health practitioners aimed at realising the health benefits of being in an outdoor natural environment and widening the range of referral opportunities available to patients[20]. Green prescriptions are a subset of a broader set of health and care activities including lifestyle advice and are generally used for long-term (chronic) conditions and mental health. A wide range of activities are included under the term 'green prescriptions', including care-farming, prescribed walking and wilderness therapy. Nature prescription groups refer specifically to treatment or therapeutic group sessions held in natural spaces such as parks, woods, gardens, beaches or upland areas. The use of green prescriptions is supported by a growing body of evidence of correlations between indices of health and wellbeing and exposure to nature (e.g. White et al 2019[21]; Bower et al 2010[22]; Shanahan et al 2016[23]; Barton and Pretty 2010[24]; Alvarsson et al 2010[25]; Repke et al 2018[26]). Doctors are increasingly thought to be willing to prescribe time spent in nature for individuals with needs that could benefit from being in an outdoor environment.

In the UK, green prescription services (see Case Studies) have generally been funded by the relevant Clinical Commissioning Group, targeting patients with generalist needs or generalist and mental health needs. Prescriptions generally consist of a 12 week programme of weekly sessions. Activities are group based and can range from arts in nature sessions to outdoor activities and games, therapeutic horticulture, green or blue exercise, physical movement, learning about ecology and systems, group sharing and practical conservation tasks and eco-psychotherapy. As part of green prescription services, public parks, private green spaces can receive funding through the commissioning of health activities that will provide cost savings to the NHS or other public services through health benefits. Payments are made based on avoided health care cost calculations. However, questions remain over whether payments will be for activities (i.e. people taking part in prescribed activities) or outcomes (i.e. actual changes in health or wellbeing).

Implementing a green prescription service requires the development of a partnership and contractual agreement between service facilitators, land owners and managers, health professionals and patient-participants. In the UK, this has generally consisted of a partnership between primary care and the third sector. Contractual agreements to deliver green prescription services can operate at the city, regional or commission group scale (see Leeds, Rotherham, Dorset, Mersey Forest). Setting up green prescription services requires relatively long-lead times to ensure the service is known among local health care centres and that local health care professionals are willing to participate through referral. The patient (participant) can contact the group facilitator or vice versa. The identification of qualified facilitator or group leader and a willing land owner is a key prerequisite.

Case Studies

Branching Out	A 12 week nature prescription project in Scotland, operating as a partnership between NHS commissioners and the Forestry Commission.
Bromley by Bow Centre	Health centre in East London is pioneering the commissioning of social prescription services, including a number of garden, park and outdoor schemes.
Care Farm UK	Provides a voice and coordinating service for care farmers, who provide health and care services in farm settings.
Ways to Wellness	Social prescribing service in Newcastle that focuses on people affected by long-term health conditions. 3,500 patients per year will benefit from services that include outdoor-based approaches to tackling inactivity.
Dartmoor NPA Naturally Healthy Project	Rooted in community engagement and targeting inactivity, Dartmoor National Park Authority's project has been working with Dose of Nature on developing its overall approach.
Exmoor NPA Moor to Enjoy project	Exmoor's project aims to increase the confidence of visitors and residents, as well as deliver a nature prescription scheme alongside a local surgery to improve the wellbeing of patients suffering low mood.
Leeds West Patient Empowerment	Social prescribing service with a strong nature-based element. NHS West Leeds Clinical Commissioning Group has funded a partnership of voluntary organisations to deliver it in conjunction with 38 GP

[20] https://www.adoseofnature.net/
[21] https://www.nature.com/articles/s41598-019-44097-3
[22] https://bmcpublichealth.biomedcentral.com/articles/10.1186/1471-2458-10-456
[23] https://www.nature.com/articles/srep28551
[24] https://pubs.acs.org/doi/abs/10.1021/es903183r
[25] https://www.mdpi.com/1660-4601/7/3/1036
[26] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6104990/

Project	surgeries.
Mersey Forest Nature4Health	Funded by Big Lottery money, a three year project to reduce health inequalities through the power of nature.
Natural Choices Project, Dorset	A suite of activities based in nature that can be made available through referral or health check, or self-referral, in the Weymouth and Portland area. Delivered by a range of environmental partners.
Rotherham Social Prescribing Service	An established social prescribing project, funded by the local CCG and with a strong element of nature-based interventions for mental health. The evaluation report was influential in setting up the Dose of Nature scheme in Cornwall

Table 1. UK Green Prescription Schemes

Cornwall Case Study: A Dose of Nature

Cornwall's high-quality environment is ideal for green prescription schemes and there is a range already in operation across Cornwall (shown below). At present green prescription schemes across Cornwall[27] are relatively '*small, local and piecemeal projects, without any central referring system or any core funding*' (Cornwall Council[28]) and have yet to be mainstreamed. The Dose of Nature project worked to encourage the delivery of nature referral schemes in a coordinated way across Cornwall[29]. The project resulted in 64 patient referrals, 48 patients waiting to complete a programme (as of 2017) with a reported increase of 69% of self-reported wellbeing, and two new self-organising support groups. *One of the main findings of A Dose of Nature has been that a referral to a group that regularly goes out into nature can benefit all sorts of people, with many health, wellbeing or social problems" (Dan Bloomfield – Dose of Nature).* In 2017 Cornwall Council consulted on a proposal to set up an LA wide nature-on-referral service in Cornwall[30] where patients will be encouraged to join groups that involve walking in natural places, and other nature-based activities to improve their health and wellbeing. The outcome from this consultation is unclear but the Dose of Nature programme remains active in Cornwall (see Dan Bloomfield[31] for more details).

Location	Description
St Austell	Iterative, immersive activities in woodland settings, run by Nature Workshops, with patient-participants on referral from Wheal Northey Health Centre in St Austell.
Exeter	The Exeter Dose of Nature group is currently (as of July 2016) being run with partners from Ecotherapy Exeter, Devon Wildlife Trust, and participating GP surgeries.
Roseland	The first Roseland Dose of Nature project focused on walking in the peninsula and, delivered by Ecotherapy Kernow, ran in spring 2015. The project helped patient-participants with a range of health conditions. The second Roseland group, focusing on patients with mild to moderate depression, is currently (July 2016) ongoing.
St Ives and Hayle	Dose of Nature group met in woodlands in West Cornwall. Nature Workshop ran the group. Referrals were made from Stennack Surgery in St Ives and Bodriggy Surgery in Hayle.
Wadebridge	Ran for a total of 46 weeks, from September 2014 to October 2015. 25 different patient-participants benefited during the course of the project. It was run by the Gaia Trust, at their farm at Treraven on the outskirts of town. Restormel Mind was a key delivery partner.
Bristol	Delivered by Into the Woods, who run workshops for wellbeing in woodland environments. They worked closely with Forest of Avon Trust, Southmead Health Centre and Bristol Public Health team.

Table 2. Green Prescription Services in SW (Source: A Dose of Nature, Dan Bloomfield)

Opportunities

A key part of green prescribing is not only ensuring that health practitioners are on board but providing access to high quality green spaces and partnering with organisations that own and manage high quality natural capital. Both the National Trust and the RSPB own and manage high-quality natural environments, and are potential providers of nature-referral spaces by engaging with existing groups or promoting the setup of new groups on their estates. The sites where green prescription activities take place need to be managed wholly or in part for nature, contain sufficient flat and/or gradually inclining paths (a minimum guideline of 100m), have sufficiently accessible safe parking provision, and perhaps most importantly be located in an area readily accessible to one of the

[27] https://www.cornwall.gov.uk/media/26898658/cornwall-nature-on-referral-plan-for-publication-2.pdf
[28] https://www.cornwall.gov.uk/media/26898658/cornwall-nature-on-referral-plan-for-publication-2.pdf
[29] https://www.adoseofnature.net/
[30] https://www.cornwall.gov.uk/media/26869866/cornwall-nature-on-referral-plan-summary-for-publication.pdf
[31] info@doseofnature.org.uk

target areas (*Dan Bloomfield*). In England, there is also evidence that the closer one lives to the coast the better one's health, and that this effect might be greater in deprived communities (Wheeler et al 2012). Setting up green prescription services on coastal areas could be a key opportunity for the National Trust and the RSPB to promote the One Coast project and potentially provide access to both volunteers and low-level funding for nature conservation on National Trust and RSPB owned sites.

Resources

Bloomfield, D., (2016) Dose of Nature: Addressing chronic health conditions by using the environment – A summary of relevant research, NERC, Online Report, Available at: https://nhsforest.org/sites/default/files/Dose_of_Nature_evidence_report_0.pdf; http://www.doseofnature.org.uk/contact-us

4.04 Results Based Agriculture Payments

Agri-environment schemes (AES) already provide an important source of funding for wildlife friendly farming. Results Based Agriculture Payment Schemes (or RBAPs), also referred to in the UK as Payment by Results (PBR), are a subset of AES which focus on payments to farmers to reward measurable improvements in farmland biodiversity. Under RBAP schemes, payments are linked to the delivery of outcomes rather than for specific capital investments or management actions. Biodiversity outcomes can be wide ranging and could include enabling or enhancing the presence of specific species. Under an RBAP scheme farmers generally have the flexibility to choose what management is required to achieve results for biodiversity, rather than following payments for prescribed actions. "*What defines a results-based scheme is that payments are made where a specific result is indeed achieved, making a direct link between the payment and the delivery of biodiversity or other environmental results on the ground*" (European Commission 2019[32]).

Finance for RBAP schemes has come largely from public sources (e.g. EU CAP), national or regional funds but there have also been private and NGO led initiatives. In some cases, RBAPs have been implemented through collective approaches, focusing on specific areas or certain communities (e.g. Burren Farming for Conservation Project, Ireland) or via individual farmers and land managers (e.g. Les Prairies Fleuries, France). RBAP schemes can include '*pure*' results-based schemes where farmers solely receive payments for outcomes, but more often there are '*hybrid'* schemes where farmers are paid partly for the successful delivery of biodiversity results and partly for capital payments to cover the upfront costs of specific actions. For example, in the Burren Farming for Conservation Scheme in Ireland, a bonus payment is made by farmers based on the scoring of the biodiversity value of the field, and upfront capital grants are also available.

In the UK, RBAP schemes are currently being trialled by Natural England in four locations, Norfolk, Suffolk, North Yorkshire and East of England, through their Payments by Result initiative[33]. Interest in implementing RBAP type schemes has been driven through efforts to prepare for exiting the EU and the development of a new Environmental Land Management Scheme (ELMS) to replace the EU Common Agricultural Policy (CAP). Under ELMs, farmers will be paid for delivering environmental services and benefits, such as improved air, water and soil quality, increased biodiversity, climate change mitigation, cultural benefits and better protection of historic environments. The aim of ELMs is to pay farmers for public goods rather than providing income support as the current, area-based scheme largely does. Environmental goods may include outcomes such as habitat protection and creation, natural flood management, water quality improvements, carbon capture, air quality, biodiversity recovery, and animal health and welfare. ELMs is planned as an alternative income stream, however it is not necessarily an RBAP scheme.

Case Studies

Burren Farming for Conservation Project, Ireland

The Burren Programme is an example of an established results based agriculture scheme operating in Ireland. The programme developed out of the Burren LIFE project first initiated in the 1990s to try to combat the loss of the unique species-rich limestone habitat. The Burren Programme is farmer-led, participating farmers co-fund action and adopt management practices and grazing regimes to conserve species-rich grasslands, improve livestock production, enhance nutrient management, remove scrub, and restore stone walls. The Burren Programme has pioneered a novel 'hybrid' approach to farming and conservation which sees farmers paid for both work undertaken (payment for actions) and, most importantly, for the delivery of defined environmental objectives. They are generally free to manage the land as they see fit (within the law). Payments for action are made through the creation of an annual farm plan containing a list of actions nominated by the farmer; jobs are individually costed and co-funded by farmers. Payments for results are made based on every eligible field of species-rich Burren grassland using a user-friendly habitat health checklist. Higher scores result in higher payments, giving farmers an incentive to manage their fields in ways that will improve their scores and their payment as well as the freedom to decide how to manage their land. Between 2010-2015, farmers in the Burren removed 214ha of encroaching scrub to protect the Burren's orchid-rich grassland. The success of the Burren programme has led to its replication on the Aran islands, through the Aran LIFE project, which worked to improve the conservation status of 1,001 ha of species-rich grassland habitats in the Aran Islands through the implementation of optimal grazing regimes and payments for results. AranLIFE utilised €2.6 million of EU and state funding to develop the best possible farm management techniques to bring three key internationally important species-rich farmland habitats to favourable condition, i.e. calcareous dry grassland, limestone

[32] European Commission http://ec.europa.eu/environment/nature/rbaps/index_en.htm
[33] Natural England RBAPs pilot https://www.gov.uk/government/publications/results-based-agri-environment-payment-scheme-rbaps-pilot-study-in-england

pavement and machair grassland. The Burren Programme has an annual budget of around €1 million funded by the Irish Department for Agriculture Food and the Marine and EU RDP funds.

Locally-led Agri-Environment Schemes and Results-Based Agri-environmental Payment Schemes (RBAPS), Ireland

The success of the Burren model in Ireland has led to this model being used to inform wider thinking on the management of farming for biodiversity across Ireland with a specific focus on locally-led or farmer led AES and the possible national development of Results Based Agricultural Payment Schemes. The Results-Based Agricultural Payment Schemes[34] (RBAPS) project has been funded since 2016, under the EU RDP, and aims to trial models to reward environmentally sensitive farming based on both the implementation of actions and evidence of positive biodiversity outcomes. Pilot schemes are in effect in Ireland for species-rich grassland in County Leitrim and for the Shannon Callows riparian meadows. At a smaller scale, the sustainable management of protected areas has been pursued through a variety of other European Innovation Projects, including the Nephin Bog SAC Upland Farming Group's Locally led AES, the Blackstairs Farming Future Partnership, and the Wicklow Uplands Council's Sustainable Uplands AES.

Natural England Payment by Results Trials, England

Natural England has implemented four Payments by Results (PBR) trials, providing funding, training and guidance for farmers at Wensleydale, Norfolk, Suffolk and East of England. The PBR pilot in Wensleydale is a partnership between the Yorkshire Dales National Park Authority and Natural England. Participating sheep and cattle farmers are rewarded for producing habitat suitable for breeding waders, or for managing species-rich meadows. Wensleydale has been chosen as a pilot as it contains a large proportion of the national upland hay meadow habitat and also breeding populations of four target bird species. Many farmers in this area are already undertaking management for these habitats under the Environmental Stewardship scheme, however, a high proportion of these schemes have already ended or are due to end. RBAP options include species-rich hay meadow or habitat for breeding waders. There is no set management prescription but a description of optimal habitats. A site area is assessed annually by the farmer and project staff, payments rates depend on the achieved score. In Norfolk and Suffolk[35], the pilot has focused on a predominantly arable area, a national hotspot for farmland birds. RBAP options include (1) winter bird food (for farmland birds and pollinators); and (2) pollen and nectar (for pollinators). The choice of options was based on the strong evidence that they are key to the survival of farmland birds and pollinators. Plots of winter bird food and/or pollen and nectar are assessed by the farmer and Natural England using a standard methodology. Assessments will also be completed on a number of 'control' farms elsewhere within the pilot area for comparison. Final payment rates for the RBAPS/PBR plots will depend on the results achieved, using a tiered approach based on how well the sown components have established and grown.

Les Prairies Fleuries, France

Since 2006, France has operated a Species Rich Grassland Programme, also referred to as the Flowering Meadows Scheme, a national competition rewarding France's best grassland meadows. As part of the competition fields are assessed using key indicator plant species, and rewards are given for farmers who manage to achieve the best agri-ecological balance on species-rich meadows and pastures on dairy farms. The contest was initially designed to test the implementation of a new style of agri-environment measure. The "Flowering Meadows" contract is results based as it allows farmers to manage their grasslands as they please as long as they achieve specific ecological outcomes. The results they seek are multiple, achieving a balance between productivity and biodiversity. The "*Concours Prairies Fleuries*" has become a national event and is now part of the prestigious *Concours Général Agricole,* putting biodiversity outcomes on a national pedestal.

Baden-Wurttemberg, Germany

A species-rich grassland scheme in Baden Wurttemberg[36], the MEKA programme has been operating from 2006. Conservation and enhancement of species-rich grassland in Brandenburg was trialled in 2008. The scheme offers a payment to farmers who manage species-rich grassland containing at least 4 key plant indicator species. The 4 species must appear within the regional catalogue of priority species. Around 4,800 farmers have engaged in the scheme covering approximately 44,000 ha of grassland, around 10 percent of all grassland in Baden-Württemberg. Farmers receive a payment of €60 per hectare for this species-rich grassland, however, it is recognised that this is a relatively small premium.

---

[34] https://rbaps.eu/
[35] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/594104/grassland-factsheet.pdf
[36] http://ec.europa.eu/environment/nature/rbaps/fiche/meka-programme-b4-species-rich-grassland-grassland_en.htm

Opportunity

Finance for a One Coast specific RBAP scheme would either have to be sourced through national funding via Defra/Natural England ELMs trial or via combined National Trust/RSPB dedicated funding. Initial set up cost/ scheme design and research would require significant outlay, with participating farmer and staff costs dependent on the number of farmers and payment rates. The majority of RBAP schemes funded in Europe have been financed via the EU CAP Rural Development Funding, via specific national government funds or through EU LIFE nature funding schemes. The key advantage would be the ability specifically to engage and target the 300+ farmers with land intersecting or within the coastal corridor. Rather than aiming for large scale funding the best approach may be to fund a competition-style approach as undertaken in the Les Prairies Fleuries case study in France, for species-rich fields within the coastal corridor.

Issues and challenges

There are a number of challenges surrounding the introduction of RBAP, including relatively high transaction and administration costs, and issues with the scoring/assessment of biodiversity value. Initial scheme design and set up is likely to require a dedicated project officer, research for scoring scheme development and identification of potential participants. However, there is a growing body of emerging practice and research that can aid development. A key aspect of RBAP is ensuring that it is co-developed with farmers, which requires the development of a community of coastal farmers, and potentially significant engagement, training and workshops to ensure they are embedded and integral to the development of the scheme. Peer to Peer development is thought to be particularly crucial to uptake. Furthermore, advice from ecologists need to be integrated within the context of practical farming operations and to improve ecologists' understanding of the realities of farming. Any RBAP schemes need to have clarity over their objectives, whether this is species-rich grassland, or increasing resources or breeding grounds for coastal wildlife. Calculating fair payment levels is also crucial and needs to relate the amount of work expected and requirements.

4.05 Carbon Finance: Voluntary Carbon Offsets

Carbon finance covers a wide range of financial mechanisms linked to Green House Gas (GHG) emission reductions, from carbon taxes to emissions trading and voluntary carbon offsets. Carbon finance is a general term applied to investments in GHG emission reduction projects or the creation of financial instruments that are tradeable on the carbon market. Carbon trading is undertaken both in statutory 'compliance markets' and in largely unregulated 'voluntary markets' outside of statutory frameworks. Many carbon finance mechanisms require international and national government regulation and interventions beyond the scope of the One Coast Project, such as mandatory emissions trading schemes and carbon taxes, however, the voluntary carbon market offers the potential for much more small-scale investment opportunities.

Voluntary carbon markets provide carbon sequestration benefits to businesses, individuals and households acting of their own volition. As part of the voluntary market, consumers fund carbon reduction programs, independent and additional to those required under current national and international law, most frequently via voluntary carbon offsets. The total volume of carbon traded in voluntary carbon markets remains small compared to compliance markets. The lack of regulatory standards in voluntary carbon markets means they have also been subject to considerable critique.

Voluntary carbon offsets are projects that carry out on-the-ground emissions reduction activities, typically measured in metric tonnes of carbon dioxide equivalents, or tCO2e. Carbon offsets are measurable, quantifiable and trackable units of GHG emission sequestration, designed to be used when reducing emissions becomes physically impossible or financially unfeasible. Offsets are purchased for a variety of reasons, most often as part of a corporation's broader environmental sustainability strategy or an individual's specific goal to reduce emissions (Ecosystem Marketplace 2017[37],2018[38]). Carbon offsets can take a variety of forms, from installing renewable energy infrastructures like wind turbines or solar panels to planting woodland that removes and stores carbon from the atmosphere (Table 3). Once established, and validated using a carbon standard, offsets can be listed and traded on voluntary markets (e.g. UK MARKIT[39]), where buyers and sellers trade on their own volition. While an offset can only be issued and retired once, it may be transacted a number of times.

Although the purchase of carbon can provide additional finance for woodland creation and peatland restoration projects, voluntary carbon offsets have historically struggled with credibility concerns, particularly around quality, quantification of carbon reductions, and double counting. Considerable work to alleviate issues with the quality and accountability of carbon offsets has taken place since 2013, with the development of global (e.g. the voluntary carbon code) and domestic standards (UK woodland and peatland carbon codes). As a means of tackling climate change there are two chief criticisms levelled against personal offsets: (1) that they do not always deliver the carbon savings they promise, and (2) they encourage people to persist in unsustainably carbon-intensive behaviours and lifestyles. There has been a widely recognised decline in the demand for, and price of, voluntary carbon offsets, with less capital investment available for the development of voluntary offsets projects (Ecosystem Market Place, 2017, 2018). At present only high quality projects which offer considerable additional co-benefits, such as biodiversity conservation or water management are thought to be finding buyers. "*End buyers are looking for "charismatic" offsets that emphasize co-benefits like economic growth or biodiversity preservation, and they are often willing to pay higher prices for them*" (Ecosystem Market Place 2018).

Project Categories	Projects with Issued Offsets	Volume of Offsets Issued in $MtCO_2e$ (2005 - Present)[4]	New Projects[5]
Agriculture – modifying agricultural practices to reduce emissions by switching to no-till farming, reducing chemical fertilizer use, etc.	87	6.7	1
Chemical Processes and Industrial Manufacturing – modifying industrial processes to emit fewer greenhouse gases.	72	63.5	0
Energy Efficiency and Fuel Switching – improving energy efficiency or switching to cleaner fuel sources.	633	127.9	8
Forestry and Land Use – managing forests, soil, grasslands, and other land types to avoid releasing carbon and/or increasing the amount of carbon the land absorbs.	170	95.3	3
Household Devices – distributing cleaner-burning stoves or water purification devices to reduce or eliminate the need to burn wood (or other inefficient types of energy).	161	23.4	0
Renewable Energy – installing solar, wind, and other forms of renewable energy production.	611	61.9	2
Transportation – increasing access to public and/or alternative transportation (like bicycling) and reducing emissions from private transportation like cars and trucks.	43	1.1	0
Waste Disposal – reducing methane emissions from landfills or wastewater, often by collecting converting it to usable fuel.	238	57.5	0

[37] *Ecosystem Market Place (2017) State of the voluntary carbon markets 2017, Forest Trends. https://www.forest-trends.org/publications/unlocking-potential/*
[38] *Ecosystem Market Place (2018) Voluntary Carbon Markets Insights: 2013 Outlook and First Quarter trends, Forest Trends. https://www.forest-trends.org/wp-content/uploads/2018/09/VCM-Q1-Report_Full-Version-2.pdf.*
[39] *MARKIT https://mer.markit.com/br-reg/public/index.jsp?entity=project*

Table 3. Categories of Voluntary Carbon Projects, 2008-2018 (source: Ecosystem Markets Taskforce - Ecosystem Market Place 2017*)*

UK Voluntary Carbon Offset Market

In the UK the Voluntary Carbon Market is not particularly large and has seen a gradual decline since peaking in 2006-2008 (Ecosystem Market Place 2017). It has suffered from many of the same issues as the global markets, with issues around standards, quality and oversupply, which are now beginning to be alleviated through the development of the UK peatland and woodland carbon codes. The outlook for voluntary carbon markets remains uncertain and has faced declines with low pricing and a lack of demand over the last decade. However, annual market analysis (Ecosystem Market Place 2018) suggests that there are opportunities on the horizon for the voluntary carbon market. The Paris Climate Agreement could provide a pathway to encourage the establishment of a unit of emissions reduction, called the Internationally Transferable Mitigation Outcome, ITMO. Although the criteria for ITMOS are still under discussion they have the potential to include voluntary carbon offsets. The aviation and shipping industries are another key potential area of expansion of voluntary carbon offset demand. The aviation industry is not covered by the Paris Climate agreement, instead the International Civil Aviation Organization (ICAO) adopted the first sector-wide carbon offsetting scheme: CORSIA. If voluntary carbon offsets are included in CORSIA this could lead to a major increase in demand, but at present this is still an unknown and may not be resolved until 2021. Despite some positive indications at present the voluntary carbon market remains relatively uncertain, potentially a high-risk for new project investment, with low levels of investment.

A range of corporates, companies and governments voluntarily offset their emissions. Historically in the UK, voluntary offsets have generally been largely purchased by customer or citizen facing corporates with an interest in cultivating an image of Corporate Social Responsibility and environmental concern. This is also the case globally, where "*the bulk of voluntary offset purchases by volume are made by multi-national, private, for-profit companies*" (Ecosystem Market Place 2018). For example, a major company may choose to offset a portion of their emissions as part of its sustainability strategy. Voluntary offset purchasers in the UK have included UK FAST IT company, Barclays, Microsoft and Kier Living. Once offsets have been purchased return buyers tend to purchase higher volumes (Ecosystem Market Place 2018). Small and Medium Sized enterprises can also be involved in offset purchases, for example, small festival and glamping companies can be interested in offsets. Although an individual traveller might offset their air travel emission, the individual offset purchase market has historically been very small scale. There have however been some high-profile individual offsets purchases for example in 2018/2017 the rock band Pearl Jam offset the emissions associated with their tour in Brazil (Ecosystem Market Place 2018).

Woodland Carbon Offsets

Woodland creation as a Voluntary Carbon Offset

Woodland creation offers a cost-effective and tangible way of creating a voluntary carbon offset, by sequestering some of the CO_2 that has been released into the atmosphere. Woodland creation already benefits from a range of grant programmes in the UK, designed to minimise the outlays by land owners and managers. Currently, active grants/finance mechanisms include The Countryside Stewardship Woodland Creation Grant; Countryside Stewardship Woodland Creation Planning Grant; Forestry Commission: Woodland Carbon Fund, Woodland Trust: moor Wood; Network Rails: Biodiversity Fund and the National Forestry Creating Woodlands Funds. Additional finance for woodland creation projects can be generated through selling carbon sequestration as voluntary carbon offset sites via the UK Carbon registry MARKIT[40].

Forestry Commission Woodland Carbon Fund

The Forestry Commission[41] provides financial support for landowners and managers for the planting of large-scale productive woodland as a means of carbon sequestration through the Woodland Carbon Fund (WCF). The standard WCF payment covers 80% of the cost of planting trees and capital establishment items such as protection items (e.g. tree guards, fencing and gates), the installation of forest roads and recreational infrastructure. Payment levels are capped at £6800 per ha, however 'priority places' (applies to proposals near to urban areas, which give access to the public on foot) receive 100% of the standard costs for planting and establishment capital items, capped at £8,500 per hectare. WCF agreements generally last for around 5 years but can be extended for 10 years. After successful establishment, an additional one-off capital payment of £1,000 per ha can be made after year 5. Landowners and managers in receipt of the WCF are still eligible to receive agricultural subsidies such as BPS. Eligibility for

[40] *MARKIT https://mer.markit.com/br-reg/public/index.jsp?entity=project*
[41] *Woodland Carbon Fund: https://www.gov.uk/guidance/woodland-carbon-fund*

WCF is dependent on size thresholds, with 10 ha or more to be planted as woodland, either as one continuous block of 10 ha of new planning in stands no more than 50m apart. The objective of the new planting must clearly remain to establish productive woodland. For any given block of woodland, integral open space is no more than 20 meters wide, no more than 0.5 hectares in extent, and completely surrounded by woodland or forest. WCF funded woodlands must include productive tree species on 70% of the net planted area, at a density of 2,000 stems per hectare minimum. It is possible to generate additional finance from selling carbon credits via registering with the Woodland Carbon Code within 2 years from the start of planting. Validation/verification of this standard provides assurance of the carbon savings and access to the voluntary carbon market.

UK Woodland Carbon Code

The UK Woodland Carbon Code[42] is a voluntary government-backed carbon standard for woodland creation projects. Woodland Carbon Units from verified WCC projects can help a company compensate for their unavoidable emissions. The code aims to ensure that woodland creation provides meaningful and measurable carbon sequestration in a transparent and clear way for potential investors, using established methods of estimating carbon capture. The Woodland Carbon Code is designed to provided assurance for potential investors by providing a measure of the quality of woodland creation, guidance for establishment and management, a standardised way of estimating and predicting carbon uptake, and guards against double counting (and selling) of carbon benefits. After new woodlands are created, they have two years to register with the Woodland Carbon Code, the process requires validation to estimate tonnes of carbon the woodland will sequester over a set period of time. Once validated, the number of tonnes of carbon predicted to be sequestered through the woodland creation projects can be marketed on the UK registry (Markit), enabling a business to buy carbon to offset their emissions and providing additional income from woodland creation. The UK Woodland Carbon Registry holds details of WCC projects and tracks the issuance, ownership and use of carbon credits, which can be used to look up a project or to see who has purchased carbon units from WCC projects. To meet the requirements of the WCC a project needs to be (1) registered with the Forestry Commission, specifying their exact location project site; (2) meet UK standards for sustainable forest management; (3) have a long term objective and management plan; and (4) use approved methods for estimating carbon capture, to demonstrate that the project delivers additional carbon benefits. By the end of 2016, 243 projects had registered with the Woodland Carbon Code. Projects meeting the Woodland Carbon Code help to meet emission targets under the UK Climate Change Act.

Case Studies: Woodland Carbon Code

Allstar Business Solutions:	Allstar, the UK's largest fuel card distributor, has bought carbon from 44 Woodland Carbon Code projects across the UK to help their customers compensate for their vehicle emissions as part of their Ecopoint scheme, launched in January 2015. The Ecopoint programme is designed to enable Allstar's wide customer base to easily measure the carbon footprint of their card holders, and turn the aggregated carbon into UK woodlands through a coordinated mitigation programme. Allstar decided on a programme of UK woodland creation and management on behalf of Ecopoint subscribers because of the multiple and local benefits UK woodlands offer in addition to carbon capture.
Bilfinger GVA	Bilfinger GVA, the UK's leading real estate advisory business, has been buying carbon from a project in Cumbria since 2015 to compensate over time for its office energy usage as part of its daily business operations. The company buys carbon equivalent to 2,000 tonnes of CO_2 every year that it cannot reduce from its office energy use. From 2016 Bilfinger GVA will be increasing the scope of its mitigation project to include emissions from business car mileage.
UK Green Investment Bank	The UK Green Investment Bank Plc has bought carbon units from three projects arounds its headquarters in Edinburgh, working with Forest Carbon. This project is managed by Tweed Forum, a charity leading integrated land and water management in the Tweed catchment.
Premier Paper Group	Premier Paper, the UK's leading independent paper merchant, since 2011 offers customers the chance to compensate over time for the production and distribution emissions of the paper they buy, with carbon from projects in Cumbria and Hertfordshire.
Waitrose	Waitrose, working in partnership with the Woodland Trust since March 2011, bought carbon from the Warcop site, to help compensate for the tailpipe emissions of their home delivery fleet. Waitrose was one of the first companies to sign up to Woodland Carbon, the Woodland Trust's carbon removal scheme. Every customer who shops online helps to plant trees to compensate for tailpipe emissions. Warcop is a Ministry of Defence site used as a military training ground for soldiers and set in an Area of Outstanding Natural Beauty in Cumbria. The trees planted by Waitrose will

[42] *Woodland Carbon Code https://www.gov.uk/guidance/the-woodland-carbon-code-scheme-for-buyers-and-landowners*

remove over 22,300 tonnes of CO_2 over the project lifetime and will create approximately 50 hectares of woodland providing homes for biodiversity. Added benefits include raising Waitrose environment and CSR credentials, developing a strong marketing message and staff engagement.

Table 4. Woodland Carbon Code Case Studies (Source: Forest Carbon)

Opportunities

Opportunities for carbon capture and storage by vegetation are present throughout the coastal corridor. Current levels of carbon storage and sequestration are highest in woodlands areas, although this is based on limited data and could underrepresent the storage potential in coastal margin habitats. The most well developed carbon offset format which fits with the aspiration of the One Coast project to create a nature rich and accessible coastal corridor is through woodland creation, however, in the future, this may be extended to saltmarsh, wetlands, and other coastal margin habitats. The policy context in Cornwall is currently very supportive of the creation of woodlands and carbon sequestration, with the recent declaration by Cornwall Council of a Climate Emergency[43], the current development of Cornwall Council Tree Canopy Charter[44], and initiatives to develop a 'Forest for Cornwall'. Cornwall Council is actively looking for actions to take in response to the recent Climate Emergency and Voluntary Carbon Offsets could be one part of the solution. However, with the benefits of carbon finance there are also responsibilities, namely to ensure the woodland project is properly managed, delivers the carbon sequestration promised and provides a transparent account of progress. There may be specific local difficulties with woodland creation in Cornwall's climate. New woodland creation opportunities maps created by the Mainstreaming Environmental Growth Project should be used to identify target sites with multiple co-benefits (Mosedale et al. 2019 in prep).

Key to the development of potential woodland carbon offset sites will be the utilisation of multiple grant sources alongside additional carbon income, and engagement with existing established actors in this sector such as the Woodland Trust who are already active in Cornwall with sites close to the coastal corridor. Additional partnerships could be developed with Forest Carbon to engage with the identification and selection of voluntary carbon offsets within or close to the coastal corridor. Woodland creation is a long-term investment and could benefit from the creation of a specific woodland fund to facilitate project development by land owners in the coastal corridor, with a blend of philanthropic funding and repayable finance to help investment in woodland projects prior to revenue generation. Although the current market is small, income for the sale of woodland carbon could help encourage existing landowners to plant additional woodland, provide new sources of income, and make woodland more attractive than traditional farming. Additional potential sources of income and examples include the Gresham House Forestry Investment, Community forestry investment via the National Forestry Company and Inheritance tax planning products. Notably, there is interest at present only in 'high quality' offset projects which offer considerable additional co-benefits, such as biodiversity conservation, and both project partners are well placed to deliver high quality '*charismatic'* offsets with multiplied benefits. Outside of woodlands, there is also notable potential to pioneer coastal wetland carbon offsets[45].

---

[43] *Cornwall Council (2019) Climate Emergency: https://www.cornwall.gov.uk/environment-and-planning/climate-emergency/*

[44] *Cornwall Tree Canopy Charter: https://www.cornwall-aonb.gov.uk/cornwall-tree-canopy*

[45] *http://bluecarbonportal.org/blog/wetlands/revised-guide-to-supporting-coastal-wetland-programs-and-projects-using-climate-finance-and-other-financial-mechanisms/...*

4.06 Payments for Ecosystem Services

Payment for ecosystem services (PES) refers to instances where the maintenance or improvement of a natural capital asset delivers an associated flow of ecological services in exchange for economic recompense (Mayrand and Paquin 2004[46]; Wertz 2006[47]). PES schemes can be more generally thought of as a "*generic name for a variety of arrangements through which the beneficiaries of ecosystem services pay the providers of those services*" (Gutman, 2006[48]). The defining factor of what constitutes a PES transaction is that they deliver or maintain a flow of specified ecosystem goods or services, such as shoreline protection, water quality improvements or carbon sequestration capabilities, and that the provision of these services merits some kind of commission or economic recompense (Jack et al 2007[49]). Payments made are based on carrying out clear interventions, such as woodland or wetland creation, peatland or river restoration, with established and evidenced links to the provision of target ecosystem goods or services. Within a rural economy perspective, PES systems are a means of rewarding those who maintain, create or improve the natural systems and habitats. The most important rationale behind PES schemes is that it can help jointly achieve conservation and livelihood objectives. PES transactions are generally voluntary and can be developed wherever a well-defined ecosystem service is available to be bought by at least one buyer, or beneficiary, from at least one provider, land owner or manager (Wunder 2005[50]). PES schemes rely on economic incentives to induce land management change, and can thus be considered part of the broader class of incentive or market-based mechanisms for environmental policy. The success of PES is largely contingent on their capacity to engage previously uninvolved actors (beneficiaries of ecosystem services) into conservation activities.

Globally, PES schemes have been developed for a range of ecosystem goods and services, from the provision of sustainable fuel wood, improvement of fish nurseries, water quality improvement and pollution regulation, carbon sequestration, shoreline stabilisation, hazard protection, nutrient regulation, soil formation, recreation and aesthetics. Some financial mechanisms already outlined in this report could also be classed as PES schemes, such as Results Based Agriculture Payments, Social Prescribing, and Visitor Giving schemes, the purpose of this section is to provide a more in-depth understanding of a range of private sector or market-based PES schemes. PES schemes have been developed and piloted since the 2000s across the UK. Looking at existing UK PES pilots, water-based PES schemes have shown the most potential, also referred to as catchment-based programmes (e.g. Upstream thinking, Fowey, SCaMP, Peak District). Water-based PES schemes have been developed where water companies or municipal governments have invested in natural capital restoration upstream to achieve financial savings through downstream improvements in water quality or water quantity. However, as highlighted previously the PES model does potentially have much broader application.

The development of a PES scheme requires establishing a clear demand for the ecosystem good or service and willing sellers or providers. Sellers can include landowners, NGOs, community groups, agri-business, large estates, pension funds, shoreline owners, LA and utilities. While demand is often driven by a buyer experiencing problems with the supply of a particular ecosystem service, most often in the UK this has been water utility companies (see Table 5). PES schemes can also arise through opportunities to increase ecosystem service provision, such as carbon sequestration. Alternatively, PES can be developed where a beneficiary has an existing dependency on ecosystem services which are under threat (e.g. water supply). Some businesses can also have a commercial stake in a local provenance which can also aid the establishment of a PES scheme.

Whilst ecosystem services are relatively well understood, linking ecosystem services benefits with the identification of a beneficiary or payee can be challenging, time consuming and requires in-depth knowledge of not only the natural capital assessment and conservation actions which can improve the supply of ecosystem services but also potential beneficiaries through understanding local stakeholders and enterprises and their supply chains. The identification of saleable ecosystem services requires consideration of: (1) Are there specific land or resource management actions that have the potential to secure an increase in the supply of the service? (2) Is there a clear demand for the service in question and is its provision financially valuable to one or more potential buyers? (beneficiary analysis). For PES schemes to operate effectively, benefits have to be additional or act in situations where ecosystem services benefits are at risk. PES schemes are also conditional on carrying out specific evidence-based actions linked to the delivery of measurable ecosystem services provision (e.g. additional tonnes of carbon sequestered), and suppliers need to remain accountable to independent verifiers to ensure a service is delivered. Provision must also be financially viable for potential buyers. In most cases, the beneficiaries and providers of ecosystem services are found in the same area. Watersheds have generally been the unit for the development of PES, but habitat or place based frameworks are also possible alternative units.

---

[46] *Mayrand, K., and 0Paquin, M., (2004) Payments for Environmental Services: A Survey and Assessment of Current Schemes. PES Unisfera.pdf*
[47] *Wertz, S., (2006) Payments for environmental services – A solution for biodiversity conservation? IDDRI wertz_pes.pdf*
[48] *Gutman, P. (2006): "PES – A WWF perspective", Presentation, WWF (www.panda.org/about_wwf/what_we_do/policy/macro_economics/our_solutions/pes/index.cfm, July 2006).*
[49] *https://sites.tufts.edu/kjack/files/2011/08/Jack_Designing-PES-PNAS.pdf*
[50] *Wunder. S., (2005) Payments for environmental services: some nuts and bolts. CIFOR. Wunder_2005.pdf*

Case Studies

A range of PES type schemes and projects are currently in action across the UK:

NAME	TYPE	DESCRIPTION	SUPPLIERS	BENEFICARIES	MECHANISM
Upstream Thinking, Fowey River Improvement Auction, Cornwall	WATER QUALITY	The River Fowey is a source of drinking water in Cornwall but suffers from sediment and pesticide pollution from agricultural practices. South West Water incurs costs treating water to make it safe to drink. The Fowey River pilot project[51] focused on the delivery of water quality-based ecosystem services using a reverse auction mechanism to distribute funds from South West Water to farmers for investing in capital items to improve water quality. Funds were used for on farm management actions that could reduce pollution levels through reduced inputs of pesticides, fertilisers and particulates to reduce downstream water treatment costs. South West Water made £360,000 available to farmers for capital investment in farm infrastructure to improve water quality. With help from advisors from the Westcountry Rivers Trust, farmers entered sealed bids to South West Water. Value for money was combined with an environmental improvement score, with 18 successful bids. The auction approach proved fast to implement with the scheme devised and implemented in 6 months and had the benefit of being farmer led. The project also faced a number of challenges, particularly around building awareness of the concept of ecosystem services. There was a particular lack of appreciation of the provisioning and regulating services which natural capital assets can provide. The project provided South West Water with considerable cost savings compared to engineering solutions. The project also revealed that paying farmers who are not demonstrating basic stewardship of the land is difficult to accept.	Farmers	South West Water Fowey Harbour Authority	Reverse Auction
Tortworth Brook Project, South Gloucestershire	WATER QUALITY	The Tortworth Brook Project is an example of the development of an integrated constructed wetland to reduce water pollution using a PES contract between Wessex Water and Torworth Estate to address issues with phosphorous discharge (Greaves et al 2014[52]; Everard 2013[53]; Defra and Wessex Water 2014[54]). The ecosystem service, in this case, was the purification of treated sewage effluent to remove nutrients, particularly phosphorus and nitrogen, entering the Tortworth Brook. To date, typical water company solutions to reducing phosphorous concentration in effluent discharge have been to install stripping mechanisms, by chemical dosing, typically with iron chloride or sulphate. For water companies stripping phosphorous is an expensive, energy, transport and resource-intensive process that increases solid waste output from the sewage treatment process. The work was jointly funded by Defra and Wessex Water and conducted in partnership with Bristol Avon Rivers Trust (BART). This used an integrated constructed wetland (ICW) solution to treat wastewater and reduced water treatment costs for Wessex Water. Interest in a PES type scheme was driven by both regulatory and financial drivers alongside environmental aspirations. The Tortworth Estate received payment from Wessex Water for the provision of land for the development of an ICW, construction of the ICW, and for the subsequent management and maintenance, such that Wessex Water's discharge consent would continue to be met. Wessex Water continues to provide regular payments to the Tortworth Estate to cover land rental, agricultural production foregone and for the continued management of the ICW. Such payments could also help facilitate the future development of additional ICWs within the catchment, which would help realise the Seller's broader ambitions of a catchment-wide wetland-based approach to ecological and water management.	Tortworth Estate	Wessex Water	Single transfer of funds, with ongoing maintenance payment for income forgone
Poole Harbour PES scheme [RSPB]; Poole Harbour Nitrogen Offsetting Project	WATER QUALITY	PES schemes linked to Poole Harbour have focused on the reduction of nitrate pollution and improved water quality, which is currently preventing development around Poole Harbour, Frome and Piddle, and affecting water quality for Wessex Water. Various PES schemes have been explored around Poole Harbour since 2012, developed by Dorset County Council, RSPB, Dorset Coastal Forum and Wessex Water. The original Defra PES Pilot in the area focused on nitrogen trading led by the RSPB and Dorset County Council and aimed to tackle the issue that new developments at Poole must be "nitrogen neutral" under the Habitats Regulations to be permitted. The Poole study found that nitrogen mitigation through reducing agricultural pollution in the catchment could cost £4.6m less over 50 years than nitrogen stripping alternatives. The legal imperative to reduce nitrate pollution based on impacts on Poole Harbour SPA creates potential buyers and potential for a nitrogen trading market. The nitrogen trading scheme aimed to enable new developments to take place as long as they pay others to reduce	Farmers	Developers and Wessex Water	Uniform Price Scheme

51 https://socialsciences.exeter.ac.uk/codebox/get_image.php?id=129
52 http://www.relu.ac.uk/landbridge/7%20M%20EVERARD%20Tortworth%20PES%20(2014-02-10%20COMPRESSED).pdf
53 https://ecosystemsknowledge.net/sites/default/files/wp-content/uploads/2013/12/EKN_Lowland_BART.pdf
54 http://randd.defra.gov.uk/Document.aspx?Document=13819_PESFinalreport.pdf

		the amount of nitrogen entering the harbour from existing sources, balancing the input from new development. The key beneficiaries are developers, who benefit from construction, but there are additional beneficiaries include the local authority and recreational users of the harbour. A proposed full nitrogen-mitigation PES scheme in the Poole Harbour catchment was not developed (Defra 2016[55]), local authorities and local developers are instead looking to land use and management changes to offset new nitrogen discharges (RSPB 2013). Given that farming is the principal cause of nitrate pollution, there were notably local authority objections to paying farmers for a reduction in agricultural nitrogen pollution which was seen as undermining the polluter pays principle. (RSPB 2013). Farmers and landowners also proved unwilling to accept long-term contracts for PES measures. However, PES-like agreements are beginning to appear in the catchment, for example the Borough of Poole Council have converted farmland to parkland at Upton Country Park to mitigate nitrogen discharges from new development, with developers purchasing 'mitigation credits' through the Community Infrastructure Levy, to date this has seen £102,000 of credits purchased (RSPB 2013). Since initial investigations in 2013, Wessex Water has piloted a separate nitrogen offsetting scheme with land managers to reduce excessive nitrate entering Poole Harbour and offset nitrate contained in the effluent discharged from Dorchester's water recycling centre. Wessex Water has paid farmers to grow cover crops that brought about reductions in the level of nitrates. A uniform price scheme by environment trading platform EnTrade. A new tool called Fundspreader ensures that farmers in the catchment who have agreed to carry out environmentally friendly farming measures are all paid the same (£/kg N) for doing so and the reward they receive is based on the amount (kg N) that they save. EnTrade developed Fundspreader with the help of Exeter University and trialled it in February 2019 after listening to feedback from the Poole Harbour farmers, who have worked closely with EnTrade since it launched out of Wessex Water in 2015.			
Lysekil Nutrient Trading Scheme, Norway	WATER QUALITY	A trial scheme whereby payments were made to mussel farmers to encourage the cultivation of Blue Mussels which filter excess nutrients and reduce eutrophication, thereby improving water quality. A lack of demand for the mussels meant that revenue could not be guaranteed and the trial scheme was unsuccessful. The expected beneficiaries were the Lysekil communities, sellers include the mussel farmers, run by an intermediaries 'community board'.	Mussel Farmers	Lysekil communities	Financial transfer
Hull Flood Risk	WATER QUANITY	The Hull flood risk project is working to address flooding issues by using urban habitats to avoid the cost of upgrading sewer capacity and reduce flood risk. The main beneficiaries include Hull City Council (on behalf of individual households) and Yorkshire Water. The project focuses on the creation of large-scale SUDS and greenspace, as well as street level SUDS. The Council is funding the project by blending finance from multiple sources. However, this layering finance has proved complex.	Multiple	Yorkshire Water, Local Residents, Hull City Council	Financial transfer
River Fal, West Cornwall	WATER QUALITY	The Westcountry Rivers Trust works to secure the preservation, protection, development and improvement of the rivers, streams, watercourses and water impoundments in the region. Among its projects is Wetland Example of Payments for Ecosystem Services (WEPES), which is restoring a section of a historic floodplain on the River Fal in West Cornwall. This includes an economic evaluation of the direct and indirect ecosystem services benefits, as well as identifying and selling the most economically beneficial services to local investors.	Farmers and land owners	Residents, Cornwall Council	Financial Transfer
River Devon Catchment	WATER QUANITY	In 2004, HSBC funded, via World Wildlife Fund-UK, sustainable flood management measures such as tree planting, erosion control and wetland restoration in the River Devon catchment in south-west England. This was a three-year project and actions were undertaken voluntarily by employees of HSBC.	Landowners and Farmers	Residents, Devon County Council	
Angling Passport, South West England	RECREATION	Landowners improve fishing beats through capital investment in infrastructure such as fencing and coppicing. Access to fishing beats is sold to anglers as tokens via the Westcountry Rivers Trust. Anglers deposit the tokens at fishing beats used; landowners then redeem the value of the tokens from the Trust. Beneficiaries are anglers, sellers include farmers and landowners, and the scheme is managed by the West Country Rivers Trust. Works aim to boost fish stocks. Schemes run by South West Water and Wessex Water pay landowners to change their land management practices to deliver water quality and	FARMERS and landowners	Anglers and South West Water	Recreational licence fees

[55] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/578005/pes-pilot-review-key-findings-2016.pdf

		quantity benefits" (Reed, 2013).			
Energy for Nature Scheme [RSPB], Somerset Levels	BIODIVERSITY CONSERVATION	The RSPB has developed an innovative "Energy for Nature" scheme in the Somerset Levels based on converting surplus biomass from wetland conservation into marketable bio-energy products on a landscape scale. Turning biomass from habitat management into energy. Energy for Nature was one of several projects funded through the third round of Defra's Payments for Ecosystem Services (PES) Pilot Scheme. The project worked to research and develop a PES based model that creates a "*sustainable funding stream to support essential conservation work whilst providing a reliable, and ecologically sustainable, source of energy to local communities*" (RSPB 2016[56]). The project took place in a wetland landscape area of the Somerset Levels and Moors and utilised the vegetation generated as a by-product of carrying out habitat management for conservation and turning it into saleable bioenergy products, such as briquettes for woodburners, loose material for biomass boilers, or electricity. The Energy for Nature scheme showed how wetland creation can be investable in the long run, providing a reliable return on investment, and offset their management costs, particularly if converting the material into electricity through anaerobic digestion (RSPB 2016). The work in Somerset suggests that cost to the RSPB c. £70,000/year could, through the adoption of this concept, generate an income of £150,000/year if markets were developed for wholesale loose biomass, or over £5 million/year if converted into and marketed as a specialist product such as biochar and sold retail (RSPB 2016). The Energy for Nature project has potential to be immediately transferable to other wetlands managed by RSPB and could also be adapted for use on heathland, while the biomass calculator could support other landowners to pursue similar projects (Defra 2015[57]).	RSPB	RSPB / Nature Conservation	Sustainable production and enterprise
Smithills Natural Enterprise Catalyst, Bolton	BIODIVERSITY CONSERVATION	This pilot project explored the potential for payments for PES on Woodland Trust owned Smithhills estate, a 1500 acre upland fringe site near Bolton. The aim was to explore the development of new enterprises that can be used to sustain natural capital on the site, specifically focusing on income for payments for ecosystem services that the site's natural capital provides and using social and private micro-enterprises. Smithhills is predominantly farmed rather than woodland, and the aim was to use the site to demonstrate the role that trees and woodland can play in providing a range of services to both people and business. The Trust also aimed to show how trees can be beneficial within the farmed environment, for example through the provision of shade and shelter to livestock. The pilot focused on services currently unsupported by functional markets but have the potential to be independent of grants or philanthropy. Two enterprises were developed during the piloting period (1) a charcoal fired social enterprise-owned food truck – designed to promote and bring locals up to the site, and (2) a 'woodshare' enterprise – aimed at involving locals in sustainable firewood production. Post pilot the Smithhills estate is still being progressed, with support of future heritage lottery funding and the planned development of a community interest company to develop additional social enterprises. The model developed by the Smithhills estate has the potential to be rolled out in other peri-urban sites. Notably, one finding from this pilot was the "*PES enterprises that are based on a suite of specific local demands for products and services may gain more traction and interest than transactions for services with more generalized social benefits – such as carbon, or biodiversity*" (the Woodland Trust, 2015[58]).	Woodland Trust	Biodiversity Conservation /Local Residents	Sustainable production and enterprise
South Pennines (Crichton Carbon Centre)	CARBON [MULTIPLE]	Development of carbon valuation methodology for a 'place-based' PES scheme with a focus on climate regulation and benefits to water quality, biodiversity and recreation. The project was led by the Crichton Carbon Centre in collaboration with IUCN Peatland Programme, URS, Defra and Natural England provided funding support. The study focused on how to develop place-based approaches for PES. It considered how marketing carbon could be combined with other possible marketable services, and development of metrics to underpin a voluntary peatland carbon code. Focused on a place-based PES scheme to deliver improvements in multiple ecosystem services in the same location through a voluntary transaction where a known quantity of ecosystem services is purchased by one or more buyers, leading to an overall increase in the provision of the service that would not have otherwise occurred. A place-based PES scheme may take place when a "premium" is charged for a core ecosystem service (such as climate mitigation or water quality) being "bundled" with a range of additional ecosystem	Landowners or Farmers	MULTIPLE LOCAL ACTORS [e.g *water companies and visitors*]	[STUDY ONLY]

[56] https://www.rspb.org.uk/our-work/conservation/projects/energy-futures-project
[57] http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=18907&FromSearch=Y&Publisher=1&SearchText=payments%20for%20ecosystem%20services&GridPage=1&SortString=ProjectCode&SortOrder=Asc&Paging=10
[58] http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=18907&FromSearch=Y&Publisher=1&SearchText=payments%20for%20ecosystem%20services&GridPage=1&SortString=ProjectCode&SortOrder=Asc&Paging=10

		services that are provided by the same management intervention. The ecosystem services considered most 'marketable' and therefore most able to generate private revenue to support their enhancement, were water quality, climate regulation, biodiversity, flood risk regulation and recreation.			

Table 5. Payments for Ecosystem Services Case Studies (Source: Defra)

Opportunities

Nationally the majority of PES schemes have been developed for water-based ecosystem services, where land management changes have been used to reduce diffuse pollutants reaching water courses (see Table 5). The majority of projects were also found to have taken place primarily on farmland, supported by the water sector, local authorities, the retail or food/beverage manufacturing industry. The driver for the water sector is often avoided costs and regulatory compliance, while interest from agri-food industries is thought to reflect its position at the start of supply chains with high exposure to consumers (Ricardo Energy and Environment 2017[59]). The ecosystems generally considered are most able to generate private revenue, including water quality, climate regulation, biodiversity, flood risk regulation and recreation.

The One Coast Evidence Base highlights the potential delivery of ecosystem services linked to natural capital assets in the coastal corridor, emphasising the high level of carbon storage in woodlands (see section 4.05), the high levels of cultural ecosystem services provided by the coastal corridor, as well as issues around soil erosion by wind and water, but notably lower levels of potential capacity around water-based ecosystem services such as water quality and quantity. The highest potential for the development of ecosystem services based payments are seen to be around cultural services (see section 4.01, 4.02, 4.03) and carbon sequestration and storage (see section 4.05), however, there is also potential to engage with a number of other PES type schemes in the coastal corridor including water-based PES schemes, pollination and soil erosion alongside the encouragement of natural capital based micro and community enterprises.

Water-based Payments for Ecosystem Services

The development of water-based PES schemes is limited in the coastal corridor as the project is not taking a catchment based approach, however based on ecosystem services mapping completed by Mosedale et al (2019 in prep) there are still a number of opportunities around improving bathing water quality in the coastal corridor and undertaking coastal and urban flood mitigation. Where PES type schemes are being set up, for example, the STARR scheme currently being run by Cornwall Council, there is an opportunity to try to engage with these projects and direct schemes to encourage implementation in the coastal corridor. Water-based PES schemes are likely to require the development of further partnerships with Cornwall Council, the Environment Agency and South West Water, and the West Country Rivers Trust. The water purification benefits of coastal margin habitats (including salt marshes, coastal lagoons and sand dunes) are increasingly being evidenced, while the benefits of woodland creation and buffer strips is already well established. A focus could be on engaging the EA and South West Water in investing in wetland creation in the coastal corridor to reduce pollutants immediately prior to entering bathing waters and freshwaters. Opportunities for wetland and woodland creation across Cornwall and within the coastal corridor are currently being finalised by Mosedale et al. (2019 in prep) and can help to direct investments to the most appropriate sites. At the same time, the increasing vulnerability of the coastline to climate change and sea level rise will put pressure on coastal margin habitats, opportunities for managed realignment and the creation of natural infrastructure could be investigated through engagement with Katrina Davis, SWEEP impact fellow, North Devon Biosphere project.

- Bathing Water Quality: Bathing water quality influences the potential for recreational use. Much like freshwater quality, natural capital assets can help to improve bathing water quality by reducing pollution from surface and ground waters. 19% of the coastal corridor was found to have some capacity to deliver benefits for bathing water quality through land use or management changes, equating to around 12,662 ha. 50% only had a low potential to deliver benefits with just 11% having the potential to deliver medium high to high benefits, some 1382 ha. Areas with the greatest potential are close to Looe, Saltash, Fowey to St Blazey, Gorren Haven, Castle wood, Carne Beach, St Anthony Head, Mawana Smith, Helford Passage, Parthhallow, Manacle Point and Dean Quarries, Kennack Sands, Mullion, Rinsey, Treen, Sennan, Portheras Cover, St Ives, Hell's Mouth to Perranporth, Wadebridge and Crackington Haven (Mosedale et al. 2019 in press).
- Flood Mitigation: The capacity of the land to mitigation flood risk is much less in the coastal corridor than in other areas in Cornwall. The majority of natural capital assets with high flood mitigation potential are around NW and central Cornwall (Mosedale et al 2019 in press). Although some 29,808 ha of the coastal corridor has some potential capacity to deliver flood mitigation benefits, almost 45% of the coastal corridor, the vast majority of this area (93%) only has a low potential to deliver flood mitigation benefits (Mosedale et al 2019 in press). Only 132 ha of the coastal corridor have 'high' potential to deliver flood mitigation benefits. Spatially some of the highest scoring areas in the coastal corridor for flood mitigation potential are immediately upstream from Wadebridge, close to Mousehole, Porthreath, between Penryn and Falmouth, and at Looe (Mosedale et al. 2019 in press).

[59] Ricardo Energy & Environment (2017) Natural capital Projects Review – Private Sector Investment Models and Scale up, Defra Evidence Project Final Report. http://randd.defra.gov.uk/Document.aspx?Document=14113_170830evid4-NaturalCapitalProjectsReviewFINALDRAFT.pdf

- ➢ Coastal Erosion: In terms of sea level rise predictions there are suggestions that over the long term (100 years) the coastal corridor will lose an area of some 258 ha along the coastline, in the medium term (the next 50 years) a loss of 144 ha and the short term (next 20 years) a loss of 74 ha.
- ➢ Fresh Water Quality: The potential of natural capital assets in the coastal corridor to regulate water quality is relatively low, just 2332 ha are scored as having any capacity to deliver water quality benefits, equating to just 3.5% of the coastal corridor (Mosedale et al. 2019 in prep). Furthermore, the majority (49%) of this area only has a low capacity to deliver benefits (Mosedale et al. 2019 in prep). Areas with high potential to provide improvements in water quality capacity include Marazion, St Ives, Porthleven, Treen, Lamorna, Hayle to Porthreath, Truro, Devoran, Perranaworthal, Ruan Lanihorne, St Austell to Par, Seaton, Hatt, Boscastle, Coombe (Bude), Marsland wood, Perran beach.
- ➢ Soil Erosion Mitigation: Soil erosion is a key cause of water quality issues. The coastal corridor experiences an average estimated loss of around 180,182 tonnes of soil per year, through water erosion, and an estimated 27,870 tonnes of soil per year, through wind erosion. Notably, predicted mean tonnes of soil eroded by the wind in the coastal corridor is almost four times higher than for the rest of Cornwall. There is considerable potential to enhance natural capital assets and change land management practice to reduce the problem of wind and water erosion across the coastal corridor, with particular needs to mitigate the effect of water erosion around Falmouth, Tamar estuary, Looe, St Martin, Saltash, Fowey, Megavisey and Gorran Haven, Truro and in the north around Bude, Camel Estuary, and Wadebridge; and wind erosion around Newquay airport, Padstow, Cracking Haven to Bude areas. Actions taken could range from the use of winter cover crops, changes to grazing regimes or planting of trees and buffer strips to reduce water and wind erosion. Introduction of catchment sensitive farming already in place in some areas of the National Trust estate could be further rolled out to the coastal corridor and tenancy agreements which stipulate that soils should be left in certain condition on expiry of the agreement.

Pollination Services

Pollination services provide crucial support for both food production and for biodiversity, as a range of crop and wild species depend upon insect-mediated pollen transfer. The coastal corridor (particularly the southern section) is thought to be of particular importance for the arable and horticultural industry with an estimated 25% of Cornwall's total area of arable and horticultural land falling within the coastal corridor. Engagement with the SWEEP 'Managing Green Space and Horticulture for Pollinators and People' project, run by Grace-Twiston Davies could help to further understand the potential delivery of enhanced pollination services for arable and horticultural farms in the coastal corridor. Mapping of opportunity areas for the enhancement of grassland for pollinators, B-Lines maps, is currently being undertaken by Grace Twiston-Davies (University of Exeter) and Jonathan Mosedale (University of Exeter) in partnership with BugLife and can help to inform areas with the greatest potential for species benefits alongside benefits for agricultural production (Mosedale et al. 2019 in press).

Natural Capital Based Ventures

Two Defra PES pilot projects, the RSPB Energy for Nature Scheme and the Woodland Trust's Nature Based Ventures projects, highlight the potential to development marketable projects from the conservation of wetlands and woodlands. In addition, the One Coast Evidence Base highlights that the coastal corridor is already a centre for enterprise and self-employment (see One Coast Evidence Base section 2.07 and 3.02.01) and therefore may be highly suited to the development of new nature-based ventures. The ideas and approaches trialled in the PES pilots have the potential for wider application and rollout across the coastal corridor to provide a sustainable funding stream to support essential conservation work. The roll out of the RSPB Energy for Nature Scheme could be assessed in conjunction with the wetland opportunities map currently being developed by Mosedale et al (2019 in prep), while the development of new enterprise to sustain natural capital on-site could be developed in partnership with the University of Exeter TEVI project and trialled on RSPB and National Trust lands prior to rolling out to new acquisition sites close to urban areas. The EU funded TEVI project has a specific remit to encourage the growth of new business and provide expert advice in this area, key contacts include Edvard Glucksman and Stephen Lowe, University of Exeter.

Issues and Challenges

There are a wide range of challenges in setting up any PES systems, including:

- PES works best when services are visible and beneficiaries are well organized, and when land user communities are well structured, have clear and secure property rights, strong legal frameworks, and are relatively wealthy or have access to resources (Mayrand and Paquin 2004).

- The development of PES efforts will need to be wary of eventual trade-offs; conservation projects that support the delivery of a given ecosystem service may conflict with the provision of other ecosystem services or may hinder other development activities. (IUCN[60]).
- Stakeholders reported that is often difficult to tie an investable business case to natural capital.
- The supply of projects which can deliver reliable income streams is relatively limited. These 'avoided cost' types of opportunities may become more feasible models for generating revenues from natural capital in future.
- High resistance to change, especially among farmers was reported by stakeholders. Farmers like to farm and therefore any "impediment" is not considered favourably.
- Issue of water-quality based PES of paying polluters.

[60] https://www.iucn.org/sites/dev/files/import/downloads/a_gateway_to_pes.pdf

4.08 Place-Based Portfolio Models

Place based portfolio models refer to where a charity, trust or social enterprise manages a group of natural capital assets (green/blue spaces such as urban parks, beaches or woodlands) to exploit multiple new revenue opportunities, including monetisable and non-monetisable (public health, amenity value, improvement of air quality) benefits. Place-based approaches can necessitate the leasing of multiple green and blue infrastructure to a charitable trust or body which is in a position to exploit new revenue opportunities. The place-based approach involves bringing together, or aggregation of, a network of natural capital assets to invest in more strategic management of the entire network.

A place-based approach is taken to enable the provision of sufficient investment opportunity to provide a more investable case, referred to as a financial aggregator vehicle. This structure could give access to funds that individual sites may be unable to bid for (e.g. corporate investments) thus making them potentially investable and able to cross-subsidise management of natural assets that may not currently generate a revenue stream. This could involve persuading the local authority to lease a portfolio of green and blue infrastructure assets to a trust who can then exploit new revenue opportunities, e.g. prescribed health activities. The place-based approach has considerable potential to manage ecosystem services provision in a way that better engages local stakeholders and fulfils ecosystem priorities. However, place-based approaches remain relatively untested in the UK (just two published cases) and these types of projects often incur high set-up costs, but they can provide sustainable funding for natural capital assets where revenue-generating activities can be used to cross-subsidise the provision of other ecosystem services. There is also potential to link to community land trusts and ownership type approaches and work in tandem with carbon finance and PES models.

Case Studies

Milton Keynes Parks Trust	The Parks Trust Milton Keynes[61] is an independent, self-financing charity which cares for over 6,000 acres (2500 hectares) of parkland and greenspace in Milton Keynes. Land under management by the Trust ranges from ancient woodlands to lakes, parkland to landscape road verges, accounting for around 25% of Milton Keynes. The Parks Trust was established in 1999 by the Milton Keynes Development Corporation to own and manage, in perpetuity, the strategic open space in Milton Keynes. It took a 999-year lease of 2000 ha and at the same time was given an endowment of around £20m in commercial rental property. The endowment was intended as an income source used to fund the work of the Trust. The Trust works to generate additional revenue from a wide range of sources including the sale of wood fuel, renting horse paddocks, donations and events. The Trust actively looks to develop new income streams in order to fund work in perpetuity. As the city has continued to grow, new parks and open spaces are being established and transferred to the Trust with an endowment. The endowment sum that is required is the capital sum that the Trust needs to invest to generate the annual income to cover the maintenance costs each year in perpetuity. Some land purchases are made possible through developments, for example, in 2015 the Trust purchased the freehold of the Linford Lakes Nature Reserve from Hanson UK. This was made possible by the Trust selling to Hanson UK, with Milton Keynes Council's consent, the mineral reserves (sand and gravel) beneath the Trust's land next to the River Ouse at New Bradwell. The Trust has been nominated to take new areas of parkland and green space from developers in the city expansion areas in the east, west and south east of the city. The Trust actively encourages all developers who are obligated under planning agreements to provide new parks and green spaces in their developments to transfer these areas to the ownership of the Parks Trust.
Newcastle Parks and Allotments Trust	The Newcastle Parks and Allotments Trust is an independent charitable trust which took over the management of 33 parks and 64 allotment sites around the city in April 2019. The aim of the Trust is to safeguard the future of the city's parks and public spaces for future generations, and a response to the 90% cuts in funding for parks in Newcastle since 2010. Newcastle Parks Trust, developed in partnership with the National Trust and communities across the city is a cooperative response to that austerity. As a charitable trust, the Parks Trust can access new funding from sources that would be off-limits to the council. The aim is also to open up parks to a greater level of community participation and ownership,

[61] https://www.theparkstrust.com/?rO=&ft=&cz=13&clat=52.042355439413214&clng=-0.7595157623291017&af=&ar=

including: (1) More community-based events; (2) Community-led decision making; (3) Opportunities for raising income – e.g. through residents establishing small businesses and cooperatives in parks. Any additional income generated (e.g. Allotment rents) will be continually reinvested in parks and allotments. The pioneering Parks Trust was developed with support from the National Trust and investment from the National Lottery through the Heritage Lottery Fund (HLF). Newcastle City Council will make a total of £9.5 million revenue contribution to the Newcastle Parks Trust over the first 10 years of operation.

Table 6. Place Based Portfolio Case Studes

Opportunities

Opportunities for place-based portfolio approach are unclear for the One Coast project.

4.09 Biodiversity Net Gain

All housing, commercial and industrial developments have the potential to impact (positively or negatively) on local biodiversity through affecting species and their habitats. Under the current planning system, residual impacts on biodiversity generally remain despite avoidance, mitigation and enhancement on-site, through residual habitat loss, fragmentation, and impacts on commonplace or undesignated biodiversity. These residual, and often unacknowledged impacts, result in a cumulative net loss in biodiversity and of the multiple socio-economic benefits we receive from the natural environment. Biodiversity net gain is an approach to development that aims to leave the natural environment in a measurably better state than beforehand by quantifying residual losses in biodiversity and providing a mechanism through which to address these either on or off site. Net impact approaches can help to finance off-site conservation efforts as net gain frameworks accept that some residual impacts are likely to occur on development sites but these need to be counterbalanced by equivalent gains preferably on-site but in some cases potentially at an off-site location. Essentially to ensure that achieving biodiversity net gain should not be a barrier to development, where developments cannot achieve net gain on-site it is possible to deliver net gain off-site. Off-site compensation can take place through developers identifying and initiating their own offsets or employing a third party to undertake an offset, under some systems in-lieu fees to finance off-site compensation can be collected and collated by the Local Authority and offsets delivered either on council owned land or through a trusted third party.

Case study

Warwickshire, Coventry and Solihull Biodiversity Offsetting Scheme

The Warwickshire, Coventry and Solihull Biodiversity Offsetting Scheme (hereafter Warwickshire scheme) was one of six Defra Biodiversity Offsetting pilots between 2012-2014 and has continued to require the delivery of no net loss in biodiversity since the end of that pilot. Under the Warwickshire scheme calculation of net losses and gains through, the application of the Defra Biodiversity Metric was made a mandatory requirement for all major and minor planning applications, and required compensation either on or offsite where net losses occur. Developers who are required to provide compensation for biodiversity loss under planning policy can choose to do so through biodiversity offsetting or in-lieu fees, conservation or compensation funds contributions. At a strategic level, off-site compensation within the Warwickshire, Coventry and Solihull Biodiversity Offsetting scheme focused on habitat connectivity linking off-site compensation delivery to implementing the delivery of the sub-regional Green Infrastructure Strategy. Off-site compensation providers, landowners, enter into 30-year agreements.

Opportunities

Delivering net gain is already supported by the National Planning Policy Framework, which states that 'planning policies and decisions should minimise impacts on and provide net gains for biodiversity' however the delivery of net gain has thus far generally been ad hoc or voluntary. In March 2019 the UK government announced an intention to make the delivery of biodiversity net gain by all developments a mandatory requirement through the forthcoming Environment Bill. Locally, Cornwall Council is planning to make the calculation of net loss and gain and the delivery of net gain a mandatory requirement by early 2020 and began the roll out of their net gain framework from September 2019. The amount of conservation finance which will be delivered through a biodiversity net gain framework is unpredictable, as it is dependent on the number and type of planning applications submitted by developers, and the extent that developers are able to achieve net gain on-site. Where off-site compensation is required, under current plans developers will have the option to either deliver off-site compensation themselves or through a third party, or make a defined financial contribution to the Council (in-lieu fee) who will then undertake offsite compensation either on Council owned land or through a third party. There is a preference for locating off-site compensation as close as possible to the impact (development) site. Given that it contains some 36% of sites allocated for development (One Coast Evidence Base, Section 3.03.06) there is likely to be a strong preference for any off-site compensation in locations close to or within the coastal corridor.

To act as a potential third party for off-site net gain compensation sites, then the project partners need to identify potential sites within their own land holdings that could have scope to act as offsets. To act as an off-site compensation site for net gain habitat creation or enhancement needs to be additional to that which is already planned. The Cornwall net gain framework is also likely to priorities sites that can deliver multiple co-benefits such as water quality improvements or flood mitigation. There is also likely to be a preference for compensation sites that extend existing ecological networks and high value biodiversity sites already under ownership by project partners. Furthermore, project partners will need to be prepared for the management of off-site compensation sites for 30 years, as best practice for offsets is achieved in perpetuity as losses at the impact site are likely to be permanent.

Issues or Challenges

- Demand for off-site compensation is unpredictable.
- A number of third parties in Cornwall could potentially act as third party offset providers; project partners may need to outline not only their expertise in habitat creation and enhancement but also their ability to deliver value for money, security and multiple benefits.
- Compensation sites, planned habitat creation/enhancement needs to clearly be additional to existing plans.
- Project partners need to be prepared to deliver, or negotiate, long term agreement and maintenance of off-compensation, up to 30 years.

4.10 Certified goods and services

Goods and services certified as having minimal or positive impacts on biodiversity may command premium prices and present a range of growth opportunities. More than three-quarters of EU citizens are willing to pay more for environmentally-friendly products. Biodiversity is increasingly being incorporated within standards and certification systems for a range of sectors, particularly sustainable agricultural, food and timber products.

Case studies

- RSPCA Welfare Standards for farmed Atlantic salmon
- RSPB - Fair to Nature
- Soil Association - Organic Standards

Opportunities

There is potential to develop a 'coastal agriculture' code that provides additional certification of goods produced within the coastal corridor which have a minimal or positive impact on biodiversity or have to deliver ecosystem services such as reductions in erosion and water quality, water storage or mitigation. As large national NGOs, both the National Trust and the RSPB are well placed for the development of a local certification system for products. The RSPB already has an unofficial certification scheme, 'Fair to Nature', which could be adapted for use in the coastal corridor to recognise the efforts of environmentally friendly production.

4.11 Catalytic Investment Funds

Catalytic investment is used to support enterprises that have a high potential impact but are struggling to raise finance or expect to generate only modest returns in the short term. Catalytic capital can help enterprises achieve the critical scale necessary to generate returns on investment, drive innovation and leverage additional investment. It is an essential research and development and upscaling tool for green enterprises.

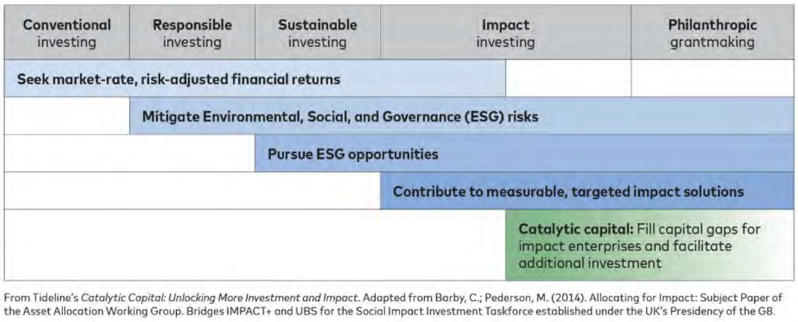


Figure 1. Catalytic Investment (Barby and Pederson 2014[62])

Case Studies

Defra Natural Capital Impact Fund	The government 25 Year Environment Plan is to '*explore the potential for a natural environment impact fund*' designed to look at innovation in designing and implementing projects that can improve the natural environment and generate revenue to pay for project costs. A longlist of project models was screened for suitability for near-term support from a natural capital facility. An initial screening considered whether a project could be supported by a natural capital facility in the near term by applying two tests: (1) whether it provides revenue streams of sufficient size and security to attract significant private sector participation; (2), whether the project model and policy conditions are developed to the point that the project could be invested in in the near term. The results of the screening highlighted the following potential opportunities for investment nationally: 1. new woodland creation, both for recreation purposes in peri-urban areas and for timber production; 2. peatland restoration; 3. biodiversity and natural capital net gain; 4. place-based strategic investments; 5. catchment services; 6. sustainable drainage systems (SUDS).

Figure 2. Screening of investment opportunities (Source Vivid Economics, Environmental Finance; Defra Natural Capital Investment Fund Study[63])

---

[62] *Barby and Pederson (2014) Allocating for Impcat: Subject Paper of the Asset Allocation Working Group, Bridges Impact+ and UBS.*
[63] *http://sciencesearch.defra.gov.uk/Document.aspx?Document=14372_BE0145StrategicOutlineCase.pdf*

Opportunities

Rather than focusing on a single approach, the provision of a targeted One Coast Catalytic Investment Fund, or seed fund, could be designed to enable the development of a suite of investable projects. An initial pot of finance targeted for PES based research and development could be provided by the National Trust and RSPB and used to raise additional philanthropic and private capital by providing grant funding for a range of investable or near investable opportunities. The fund could be used to catalyse further investment into the sector over time and generate match funding to help a number of PES-based One Coast projects to get off the ground and provide future returns on investment for the project partners. This fund would be designed to support projects in moving towards generating revenue, the transition to a cash flow generating natural capital project over the long term. A tender or auction-based system could be implemented in partnership with an organisation such as Cornwall Council (Grow Nature Seed Fund) and the TEVI project at the University of Exeter. This fund could be raised through project partners, foundations, corporates, Corporate Social Responsibility (CSR) budgets, High Net Worth Individuals and philanthropists to provide specialist finance, legal and other skills to help develop business plans for natural capital projects to improve their presentation to investors.

5. Summary

The landscape scale ambitions of the One Coast project require careful consideration of possible sources of finance and the establishment of a One Coast investment plan. Based on the findings of the One Coast Evidence Base, this review has outlined a range of possible finance mechanisms which could be used for the One Coast project and represents the first step towards the development of a strategic plan and investment plan for the One Coast project. The priority investment opportunities and recommended actions are summarised below:

- Woodland creation: Woodland creation is currently a key priority for Cornwall Council and has the potential to attract multiple grants for capital setup and maintenance costs and generate a reliable return on investment through both wood products and carbon finance. Initial set up costs can be reduced through the use of Countryside Stewardship Woodland Creation Grants or the Woodland Carbon Fund, with return on investment being provided through the sale of carbon sequestration as a voluntary carbon offset and sale of wood based products. In some cases this finance could also be bundled with net gain off-site compensation to provide higher returns and generate capital for investment in less profitable habitat creation. Voluntary Carbon Offsets could be marketed nationally via the MARKIT tool or locally to, for example, transport and logistics firms with high carbon footprints, air transport passengers and airlines, large client facing business or even communities. The development of new woodlands for biodiversity and profit could be undertaken in partnership with established bodies in the sector, such as Forest Carbon, the Forestry Commission and the Woodland Trust. The policy context in Cornwall is currently very supportive of the creation of woodlands and carbon sequestration, with the recent declaration by Cornwall Council of a Climate Emergency[64], the current development of Cornwall Council's Tree Canopy Charter[65], and initiatives to develop a 'Forest for Cornwall'. Cornwall Council is actively looking for actions to take in response to the recent Climate Emergency and Voluntary Carbon Offsets could be one part of the solution. Notably, interest in a Voluntary Carbon Offsets market nationally is thought to be restricted to 'high quality' offset projects which offer considerable additional co-benefits, such as biodiversity conservation, and both project partners are well placed to deliver high quality '*charismatic'* offsets with multiplied benefits. Outside of woodlands, there is also notable potential to pioneer coastal wetland carbon offsets[66] but research and practice in this area are much less developed.

- Transient Visitor Levy and/or Voluntary Visitor Payback/Giving: Cornwall's coastline and the coastal corridor are inextricably linked to the tourism industry, with conservative estimates of some 2.26 million visitors per year to the coastal corridor (excluding beaches and coastal restores) and higher estimates of around 14 million per year. The significance of the coastal corridor for the Cornish tourism industry and the volume of visitors means that consideration must be given to the potential for the tourism sector to help finance the One Coast project, either via a Transient Visitor Levy (tourist tax) and/or a Voluntary Visitor Giving Scheme. Cornwall Council is already investigating the introduction of a visitor tax at the county scale. There is a strong argument that the tax revenue from a TVL should also be used to enhance natural capital assets in the coastal corridor as a chance for both visitors and the tourism industry to support a key source of their enjoyment (visitors) and income (tourist industry). Investing in the coastal corridor would also be a positive action for the Council as this would support the future growth potential and resilience of the Cornish Tourism industry and could encourage increased visitor numbers. The TVL would also reflect the true cost of tourism in terms of recreational pressure on the coastal corridor and the need for the tourism industry to invest for its future. Prior to the development of a LA scale TVL the project partners could develop trial schemes with large tourist corporates such as Airbnb and book.com, introduce a specific TVL for National Trust holiday accommodation, and support and highlight the need for a TVL to Cornwall Council, and specifically emphasise the need to allocate revenue from the tax towards natural capital investment in the coastal corridor as a means to invest in the future development of the tourism industry. A voluntary Visitor Payment (VP) scheme is well suited to the One Coast project as VP schemes are thought to be most successful when visitors can contribute towards a specific project that is delivering tangible benefits to an area they visited. A VP linked to the coastal corridor could be developed in conjunction with the South West Coast Path Association, using app based payment or local collections. To achieve the necessary scale of a VP for the One Coast project, there is a clear need to achieve signup of a large number of businesses. Voluntary VP is also a resource mobilisation technique that both of the One Coast project partners are already well accustomed to and are well suited to upscaling using in-house expertise. VP also represents an awareness raising opportunity for the One Coast project. The development of a large scale VP scheme may necessitate a one-off grant aid to kick start the project and a percentage of

[64] Cornwall Council (2019) Climate Emergency: https://www.cornwall.gov.uk/environment-and-planning/climate-emergency/
[65] Cornwall Tree Canopy Charter: https://www.cornwall-aonb.gov.uk/cornwall-tree-canopy
[66] http://bluecarbonportal.org/blog/wetlands/revised-guide-to-supporting-coastal-wetland-programs-and-projects-using-climate-finance-and-other-financial-mechanisms/...

collected finance reinvested to support long term viability of the scheme. Key partners for the development of VP include Visit Cornwall, the SW Coastal Path Association and the Cornwall AONB.

- Community Land Purchase: Some 37% of Cornwall's population live and work in the coastal corridor, however many Cornish residents may not be able individually to own coastal land any larger than their back garden but could be interested in investing in shares of coastal land. For the One Coast project, developing a network of CLP groups along the coastal corridor could offer an additional route for land purchase for project partners, and provide committed and long-term volunteer groups to support the restoration and on-going management of natural capital assets. The project partners could take on a leadership role in the development of a Cornwall-wide network of CLP groups along the coastline, working in partnership and providing expert knowledge and support where necessary for CLP groups. Initial set up work would be needed to catalyse and gauge the potential level of interest including an initial survey of existing community groups and residents. Awareness raising on the importance of the coastal corridor and the potential for CLP would be a critical first step.

- Biodiversity net gain: Demand for off-site net gain compensation sites is unpredictable, however the Cornwall net gain framework is likely to prioritise sites which can deliver multiple co-benefits such as water quality improvements or flood mitigation. There is also likely to be a preference for compensation sites which lie close to impact sites and extend existing ecological networks and high value biodiversity sites already under ownership by project partners. Net gain frameworks could potentially provide both capital and 30 years of maintenance and management costs for habitat creation but will require proactive identification of viable and cost-effective delivery sites, ideally close to potential impact sites. To act as a potential third party for off-site net gain compensation sites, project partners need to identify potential sites within their own land holdings which could have scope to act as offsets. To act as an off-site compensation site for net gain habitat creation or enhancement needs to generate a specified number of units and be additional to creation or enhancement which is already planned. Furthermore, project partners will need to be prepared for the management of off-site compensation sites for 30 years.

- Green Prescription Schemes: There are a number of active green prescription schemes across Cornwall linked to the 'Dose of Nature' project. Green prescription schemes are unlikely to generate substantial finance but can be used to raise the profile of the One Coast project, and generate some income for further investment in habitat creation and enhancement. A key part of green prescribing is not only ensuring that health practitioners are on board but providing access to high quality green spaces and partnering with organisations that own and manage high quality natural capital. Both the National Trust and the RSPB own and manage high-quality natural environments, and are potential providers of nature-referral spaces by engaging with existing groups or promoting the setup of new groups on their estates. Setting up green prescription services on coastal areas could be a key opportunity for the National Trust and the RSPB to promote the One Coast project and potentially provide access to both volunteers and low-level funding for nature conservation on National Trust and RSPB owned sites.

- Results Based Agriculture and Certification Schemes: Enclosed grasslands and farmlands dominate the coastal corridor, covering some 64% of its area. The large area of enclosed grasslands and farmlands means that any effort to create a nature-rich and accessible coastal corridor needs to consider approaches for enhancing agricultural land for biodiversity and multiple ecosystem service provision. National agri-environment schemes (AES) already provide an established and important source of funding for wildlife friendly farming. For the coastal corridor, project partners could consider piloting a results-based agriculture scheme providing bonus payment for farmers to reward measurable improvement in farmland biodiversity. Alternative options could be to initiate a small scale competition for the most species diverse coastal farmland, with dedicated bonus payment for coastal farmers delivering measurable biodiversity improvement in terms of species richness on a field level scale. The delivery of a greater level of biodiversity could be linked to a specifically designed local certification scheme that provides recognition and premium product benefits for participating farmers.

- Payments for Ecosystem Services: Nationally the majority of PES schemes have been developed for water-based ecosystem services, where land management changes have been used to reduce diffuse pollutants reaching water courses. The majority of projects were also found to have taken place primarily on farmland, supported by the water sector, local authorities, the retail or food/beverage manufacturing industry. The driver for the water sector is often avoided costs and regulatory compliance, while interest from agri-food industries is thought to reflect its position at the start of supply chains with high exposure to consumers. The One Coast Evidence Base highlights the potential delivery of ecosystem services linked to natural capital assets in the coastal corridor, emphasising the high level of carbon storage in woodlands, the high levels of cultural ecosystem services provided by the coastal corridor, as well as issues around soil erosion by wind and water, but notably lower levels of potential capacity around water based ecosystem service such as water quality and quantity. Any PES scheme would likely need to be developed in partnership with Cornwall Council, the tourism industry, the Environment Agency and SW Water utilities. Targeted creation of wetlands, coastal margins or woodlands could be used to try to improve bathing water quality, reduce flood risk and sequester carbon. The set-up of specific Payments for Ecosystem Services schemes linked to soil erosion, bathing water quality, or carbon storage and sequestration could be a key pathway to encourage environmental improvement in the One Coast project areas.

- Natural Capital Ventures: Two Defra PES pilot projects, the RSPB's Energy for Nature Scheme and the Woodland Trust's Nature Based Ventures projects, highlight the potential to develop marketable projects from the conservation of wetlands and woodlands. In addition, the One Coast Evidence Base highlights that the coastal corridor is already a centre for enterprise and self-employment and therefore is likely to be highly suited to the development of new nature-based ventures. The ideas and approaches trialled in the PES pilots have the potential for wider application and rollout across the coastal corridor to provide a sustainable funding stream to support essential conservation work. The roll out of the RSPB Energy for Nature scheme could be assessed in conjunction with the wetland opportunities map currently being developed by Mosedale et al. (2019 in prep), while the development of new enterprises to sustain natural capital on-site could be developed in partnership with the University of Exeter TEVI project and trialled on RSPB and National Trust lands prior to rolling out to new acquisition sites close to urban areas. The EU funded TEVI project has a specific remit to encourage the growth of new business and provide expert advice in this area.

- Investment Readiness or Catalytic Investment Fund: Rather than focusing on a single approach, the provision of a targeted One Coast Catalytic Investment Fund, or seed fund, could be designed to enable the development of a suite of investable projects. An initial pot of finance targeted for PES based research and development could be provided by the National Trust and RSPB and used to raise additional philanthropic and private capital by providing grant funding for a range of investable or near investable opportunities. The fund could be used to catalyse further investment into the sector over time and generate match funding to help a number of PES based One Coast projects to get off the ground and provide future returns on investment for the project partners. This fund would be designed to support projects in moving towards generating revenue, and the transition to a cashflow generating natural capital project over the long term. A tender or auction-based system could be implemented in partnership with an organisation such as Cornwall Council (Grow Nature Seed Fund) and the TEVI project at the University of Exeter.

6. References

Alvarsson et al. (2010) Stress Recovery during Exposure to Nature Sound and Environmental Noise, Int. J. Environ. Res. Public Health 2010, 7(3), 1036-1046; https://www.mdpi.com/1660-4601/7/3/1036.

Barby and Pederson (2014) Allocating for Impcat: Subject Paper of the Asset Allocation Working Group, Bridges Impact+ and UBS.

Barton, J., and Pretty, J., (2010) What is the Best Dose of Nature and Green Exercise for Improving Mental Health? A Multi-Study Analysis, Environ. Sci. Technol.201044103947-3955. https://pubs.acs.org/doi/abs/10.1021/es903183r.

Bloomfield, D., (2016) Dose of Nature: Addressing chronic health conditions by using the environment – A summary of relevant research, NERC, Online Report, Available at: https://nhsforest.org/sites/default/files/Dose_of_Nature_evidence_report_0.pdf; http://www.doseofnature.org.uk/contact-us

Bowler et al. (2010) A systematic review of evidence for the added benefits to health of exposure to natural environments, BMC Public Health, 10:456. https://bmcpublichealth.biomedcentral.com/articles/10.1186/1471-2458-10-456.

Community Land Advice (2019) Community Land Advisory Service, Webpage, Available at: https://en.communitylandadvice.org.uk/en/buying-land

Cornwall Council (2012) Economy and Culture Strategy Evidence Base - https://www.cornwall.gov.uk/media/3624007/Economy-and-Culture-Strategy-Evidence-Base.pdf.

Day, B., and Smith, G., (2018). Outdoor Recreation Valuation (ORVal) User Guide: Version 2.0, Land, Environment, Economics and Policy (LEEP) Institute, Business School, University of Exeter.

Ecosystem Market Place (2017) State of the voluntary carbon markets 2017, Forest Trends. https://www.forest-trends.org/publications/unlocking-potential/

Ecosystem Market Place (2018) Voluntary Carbon Markets Insights: 2013 Outlook and First Quarter trends, Forest Trends. https://www.forest-trends.org/wp-content/uploads/2018/09/VCM-Q1-Report_Full-Version-2.pdf.

Forestry Commission (2013) A framework for sharing experiences of community woodland groups, Available at: https://www.forestresearch.gov.uk/documents/190/FCRN015_RZLgaTl.pdf

Gutman, P. (2006): "PES – A WWF perspective", Presentation, WWF (www.panda.org/about_wwf/what_we_do/policy/macro_economics/our_solutions/pes/index.cfm, July 2006).

Jack, K., et al (2007) Designing Payments for Ecosystem Services: Lessons from Previous Experience with Incentive-based Mechanisms, https://sites.tufts.edu/kjack/files/2011/08/Jack_Designing-PES-PNAS.pdf.

Mackenze, F.D., (2012) Places of Possibility Property, Nature and Community Land Ownership, Wiley Blackwell.

MacLeod, C., (2017) The future of Community Land Ownership in Scotland, A Discussion Paper, Highlands and Islands Enterprise, Online report, Available At: http://www.calummacleod.info/couchuploads/file/the-futureofcommunitylandownershipinscotlandadiscussionpaperfinal-2.pdf.

Mayrand, K., and Paquin, M., (2004) Payments for Environmental Services: A Survey and Assessment of Current Schemes. PES Unisfera.pdf.

Mosedale et al. (2019 in prep) Opportunity and Nature Network Maps for Cornwall. ESI, University of Exeter.

Parker, C. et al. (2012) The Little Biodiversity Finance Book: a guide to proactive investment in natural capital (PINC) 3rd ed., Oxford: Global Canopy Programme. Available at: http://globalcanopy.org/sites/default/files/documents/resources/LittleBiodiversityFinanceBook_3rd edition.pdf.

Reed et al. (2013) Visitor Giving Payment for Ecosystem Service Pilot Final Report, Defra, London. http://randd.defra.gov.uk/Document.aspx?Document=11917_VGSPESPilotFinalReportFeb14.pdf

Repke et al. (2018) How does nature exposure make people healthier?: Evidence for the role of impulsivity and expanded space perception. PLoS One. 2018; 13(8): e0202246. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6104990/

Shanahan et al (2016) Health benefits form nature Experiences Depend on Dose, Scientific Reports,6, 28551[1] https://www.nature.com/articles/srep28551.

Somper, J., (2011) Funding trends – the implications for future nature conservation. ECOS Spring, pp.32, 1, 34–42. Available at: https://www.banc.org.uk/ecos-32-1-spring-2011-funding-trends-the-implications-for-future-nature-conservation-jonathan-somper/

SWRC (2016) SW Coast Path Monitoring and Evaluation Framework, Year 5 (2015) Key Findings, Produced on behalf of the SW Coast Path Team.

SWRC (2018) Cornwall Visitor Survey 2018/19 Quarterly update, Produced on behalf of Visit Cornwall.

The Woodland Trust (2011) Community ownership for woodland management and creation – Community Woodland Ownership, Research Report, Available at: https://www.woodlandtrust.org.uk/mediafile/100263178/rr-wt-71014-community-ownership-for-woodland-management-and-creation-.pdf?cb=f6144e3b40534c458e896052a12a9132

Visit England (2012) Visitor payback toolkit, Available at: https://www.visitengland.com/sites/default/files/downloads/visitor_giving_helpsheets.pdf

Wertz, S., (2006) Payments for environmental services – A solution for biodiversity conservation? IDDRI wertz_pes.pdf

Wheeler et al. (2012) Does living by the coat improve health and wellbeing? Health Place, 18(5). 1198-1201. oi: 10.1016/j.healthplace.2012.06.015.

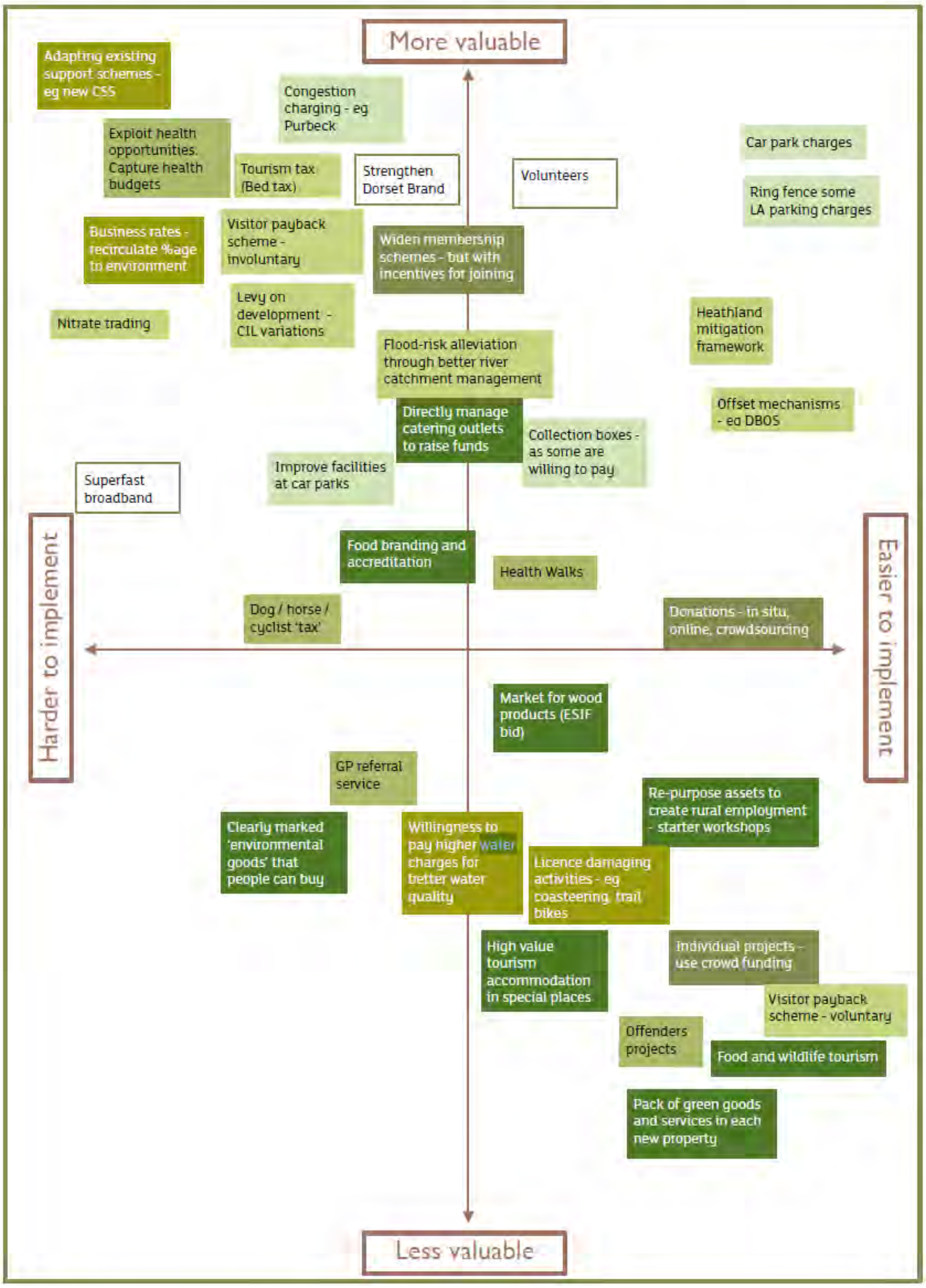
White et al (2019) Spending at least 120 minutes a week in nature is associated with good health and wellbeing, Scientific Reports, 9, 7730 (2019). https://www.nature.com/articles/s41598-019-44097-3

White et al. (2013). Coastal proximity, health and well-being: results from a longitudinal panel survey. Health Place; 23:97–103.

Wunder. S., (2005) Payments for environmental services: some nuts and bolts. CIFOR. Wunder_2005.pdf.

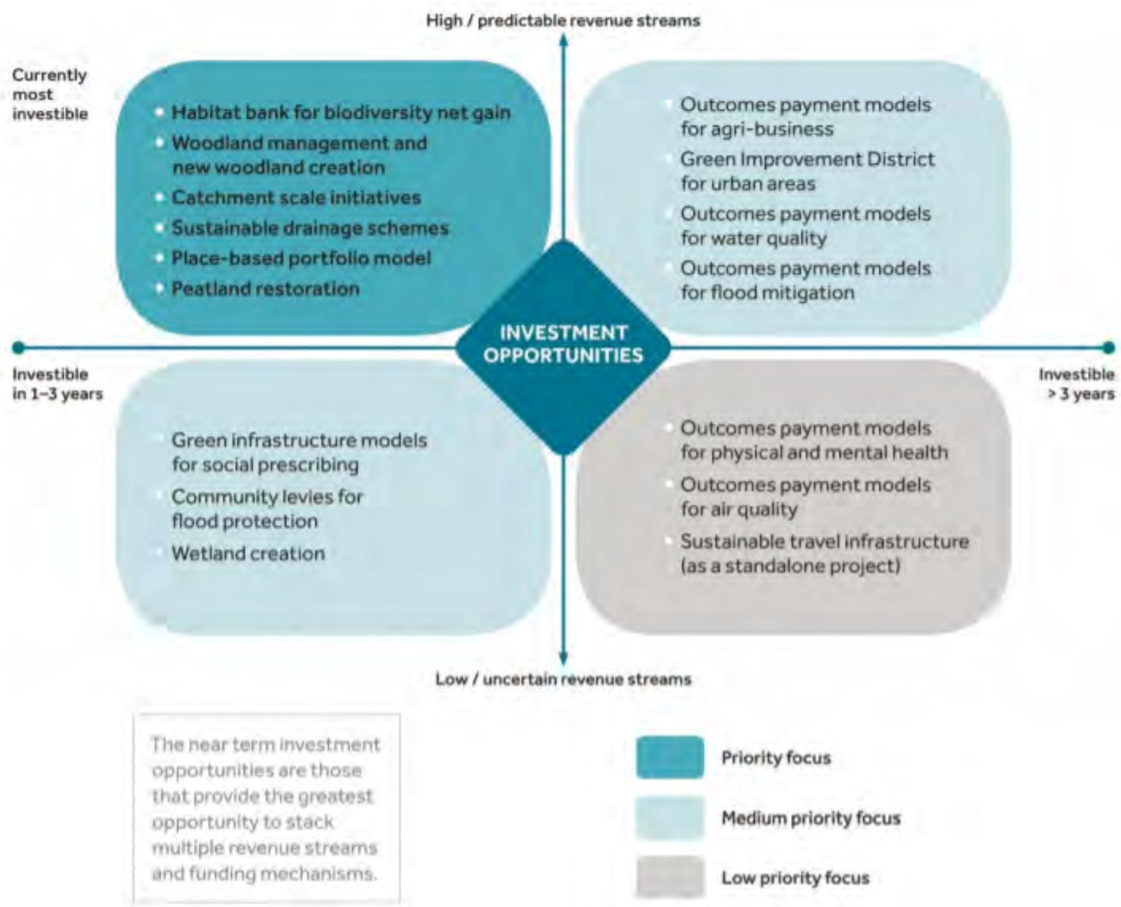
7. Appendices

Appendix 1. Dorset's Environmental Economy: Financial Mechanisms[67]



[67] https://jurassiccoast.org/wp-content/uploads/2016/02/Dorsets-Environmental-Economy-Final-Report-Dec-2015.pdf

Appendix 2. Greater Manchester Natural Capital Investment Plan: Investability Assessment of a pipeline of potential natural capital project types[68]



[68] https://naturegreatermanchester.co.uk/project/greater-manchester-natural-capital-investment-plan/

One Coast Evidence Base:

An Environmental and Economic Review of the Cornish Coastal Corridor

---

Executive Summary

For the purpose of this review, the Cornish coastal corridor is defined as the continuous strip of land stretching 1km inland from mean high water. Although Cornwall has a relatively sparse overall population density the coastal corridor is interspersed with multiple dense coastal settlements (e.g. St Austell, Truro, Falmouth, Bude, Newquay, Saltash and Penzance). The concentration of urban settlements in the coastal corridor make it a focal point for much of Cornwall's economic activity and settlements. Cornwall's coastal corridor is composed of an extensive range of natural features, including granite cliffs, small rocky coves and headlands, mudflats, sand dunes, sandy beaches and estuaries alongside wooded valleys, grazing pastures and arable lands. The coastline itself ranges from an extensive network of indented coves, long river estuaries and creeks, to exposed headlands, sheer cliffs and large sandy beaches. Moving inland from the coastline, the coastal corridor contains a range of habitats, from sheltered broadleaved wooded estuaries, to exposed coastal heathlands and semi-natural grassland, often with abrupt transitions into agricultural improved grasslands, horticultural and arable areas, urban and suburban settlements.

- A high population density: Between 32%-37% of the population of Cornwall live in the coastal corridor. Although this population is relatively dispersed along the coastal corridor, with 42% of the population in urban areas and 58% in rural areas, the population density in the coastal corridor is more than twice that of the rest of Cornwall (3.04 usual residents per ha) and by 2030 this could rise to 3.4 usual residents per ha.
- An older population: Usual residents of the coastal corridor, and its immediate surrounding area, have a higher mean age and median age compared to the rest of Cornwall. Consequently, the coastal corridor contains a slightly lower percentage of economically active residents (-3%) than the rest of Cornwall (2011), and a higher percentage of economically inactive residents who are retired (+2%). The age differential across Cornwall is predicted to grow, with 31% of the population predicted to be 65 or over by 2030. The ageing population in Cornwall is likely to grow in the future and place higher demand on services such as health and care provision in the corridor.
- A generally wealthier population with pockets of deprivation: Living in the coastal corridor is expensive. Average residential property price within the coastal corridor was estimated to be around £336 thousand pounds, 27% higher than the average for the whole of Cornwall. There is a notably higher percentage of usual residents of the coastal corridor who are employed as managers, directors and senior officers and in professional occupations (39%) compared to the rest of Cornwall (33%). Six neighbourhoods which intersect the coastal corridor rank within the 10% most deprived Lower Super Output Areas (LSOAs) in England, out of a total of seventeen neighbourhoods which rank amongst the 10% most deprived in England across the whole of Cornwall (35%). Eight neighbourhoods which intersect the coastal corridor are within the 20% most deprived LSOAs in England, out of a total of twenty-seven neighbourhoods in Cornwall classed as amongst the 20% most deprived in England (30%).
- A hotspot for enterprise and self-employment. 24% of economically active residents in employment in the coastal corridor are self-employed, 2% higher than for the rest of Cornwall and 10% higher than the national average (ONS 2011). 44% [9225] of all enterprises in Cornwall registered with Companies House fall within the coastal corridor, this excludes enterprises not registered for VAT or PAYE. Within the coastal corridor the density of enterprises is 0.14 per ha while it drops to 0.039 per ha for the rest of Cornwall. The coastal corridor is of particular importance for the following sectors: tourism, recreation and leisure, education, retail, professional scientific and technical services, finance and insurance, food and beverage sectors, construction and real estate, and marine based business.
- A centre for economic productivity*:* The coastal corridor could contribute an estimated 38-44% of Cornwall's total Gross Value Added (GVA*)*. It is important to note that these estimates are subject to the effects of commuting and variations in the age structure of populations. The largest contributions to the coastal corridor's GVA are derived from public administration, education and health (23%); real estate (19%); distribution and transport, accommodation and food (18%); and construction (12%). The coastal corridor is particularly important for financial and insurance activities (72% of total GVA from this sector), information and communication (69%), construction (68%) and other services and household activities (51%).

- **Vital to the Cornish tourism industry:** Tourism is a main driver of the Cornish economy, it is also a sector which is "inextricably linked to Cornwall's unique environment, including its coastline and cultural heritage" (Cornwall Council 2012[1]). 53% of tourist sites lie within or intersect the coastal corridor. An estimated 5.34 million day/staying visits per year are made to coastal areas in Cornwall (28% of total) (SWRC 2016[2], 2018[3]). Conservative estimates suggest that the coastal corridor, excluding beaches and coastal resorts, receive an estimated 2.26 million visitors per year (SWRC 2016[4]), however, this number could be as high as 14.88 million visitors per year (SWRC 2016). Coastal areas are estimated to be linked to a tourist spend of around £666 million per year, and the coastal corridor an estimated £178 million per year, equating to on average 10% of the total visitor spend in Cornwall and 26% of coastal spend (SWRC 2016, 2018[5]).
- **A focal point for real estate development**: New housing and employment uses are planned for the coastal corridor, and some 36.4% of all 'allocation sites' (by area) lie within or intersect the coastal corridor. Based on estimated dwelling numbers for housing-based allocations, 49.5% of allocated dwellings will be in sites which intersect or lie within the coastal corridor.
- **One-third of Cornwall's best and most versatile agricultural land:** Cornwall's economy is still more reliant on agricultural production and food processing than much of the rest of UK (6% of GVA and 30% of employment). Despite having 10% less agricultural land than the rest of Cornwall, one-third of Cornwall's best and most versatile agricultural land lies within the coastal corridor and the corridor is of particular importance for arable and horticultural farm types. Approximately 372 farms have land intersecting the coastal corridor, 8.2% of the total estimated farms in Cornwall. These farms currently benefit from an average Common Agricultural Policy Basic Payment of £241/ha. 33% of agricultural land in the coastal corridor has received payments for environmental improvements, through Agri-Environment Scheme Agreements with a total annual value to agreement holders of £1.597 million and an average payment of £115/per ha.
- **A landing site for fisheries and aquaculture:** Total landed value of the fisheries sector in Cornwall is approximately £23.5 million. The aquaculture industry has a total landed value of £4.2 million. At some locations the development of the aquaculture industry has been directly influenced/constrained by the coastal corridor due to the dependency of aquaculture on pristine water quality. At present only 26% of estuaries and 44% of coastal areas are assessed as being of good ecological quality which limits the capacity of aquaculture to develop close to the coastal corridor.
- **Quarrying and Mining**: There are 50 active mines and quarries, 26% [13] of these are sited within or very close to the coastal corridor (GeoIndex Onshore 2019).
- **Natural Capital Assets**:
    - A wide range of semi-natural habitats, natural capital assets, are present across the coastal corridor. Natural capital assets are estimated to cover 87% of the coastal corridor.
    - The vast majority of the corridor consists of enclosed grasslands (73%), woodlands (13%) and coastal margins (9%).
    - Comparing the coastal corridor to the rest of Cornwall shows a lower proportion of semi-natural grasslands (-4%), and a notably higher percentage are of woodlands (+3%), and, as to be expected, coastal margin habitats (+6%).
        - Woodlands cover some 11% of the coastal corridor, by percentage area, compared to just 9.2% of the rest of Cornwall. This includes an estimated 1,472 ha of ancient and semi-natural woodlands, 21% of the total amount in Cornwall.
        - The coastal corridor is a significant reserve for neutral and calcareous semi-natural grassland, containing 81% of all calcareous grasslands and 53% of all neutral grasslands in Cornwall, but a much lower percentage area of acid grasslands compared to the rest of Cornwall.
        - Freshwater habitats cover only 0.12% of the coastal corridor by area, accounting for 5.2% of the total extent of freshwater habitats across Cornwall. Twelve BAP priority rivers run through the coastal corridor, around 16.6km, 48% of the total length of priority rivers across Cornwall.
    - Woodlands have the potential to deliver the largest range of ecosystem services, however coastal margins may provide the most valuable services through leisure and hazard and climate regulation, while by virtue of their extent, enclosed grasslands have significant potential for improvement in ecosystem service delivery. Coastal margin habitats provide

[1] *Cornwall Council (2012) Economy and Culture Strategy Evidence Base - https://www.cornwall.gov.uk/media/3624007/Economy-and-Culture-Strategy-Evidence-Base.pdf*
[2] *Please note that these data exclude regular non-tourism related residential use such as dog walking.*
[3] *SWRC (2018) Cornwall Visitor Survey 2018/19 Quarterly update, Produced on behalf of Visit Cornwall.*
[4] *SWRC (2016) SW Coast Path Monitoring and Evaluation Framework, Year 5 (2015) Key Findings, Produced on behalf of the SW Coast Path Team.*
[5] *Observatory of the Cornwall Marine Leisure Industry Draft in preparation 2010. Nautisme Espace Atlantique Project, Cornwall Development Company.*

ecosystem services to both adjacent terrestrial and marine habitats, for Cornwall the ecosystem services of greatest financial value are thought to be recreation (tourism) and coastal defence.

- Physical Flow Accounts
  - Regulating Services - Climate regulation potential (Carbon storage and sequestration): Soils and vegetation in the coastal corridor are estimated to store approximately 9 million tonnes of carbon, equating to around 14.3% of Cornwall's total stored carbon. Soils store an estimated 15 times the amount of carbon as above ground vegetation. The coastal corridor stores 20% of Cornwall's total above ground carbon storage. The coastal corridor is estimated to have the potential capacity to sequester an additional 55 thousand tonnes of CO_{2e} per year, around 17% of the total amount potentially sequestered each year in Cornwall.
  - Regulating Services - Erosion Mitigation Potential: Soils perform a variety of key ecosystem services such as nutrient cycling, regulating water and carbon storage. The erosion of soils has major implications not only for farm productivity, but also by reduced water quality and avoided cost as eroded soils often need to be removed from roads, reservoirs etc. At present the coastal corridor experiences an average estimated loss of around 180,182 tonnes of soil per year through water erosion, and 27,870 tonnes of soil per year through wind erosion. The predicted mean tonnes of soil eroded by wind in the coastal corridor is almost four times higher than for the rest of Cornwall. Sea level rise could result in the loss of some 74ha of the coastal corridor in the next 20 years. There is considerable potential to enhance natural capital assets and change land management practice to reduce wind and water erosion.
  - Regulating Services - Air Quality Amelioration Potential: Cornwall has one of the highest amounts of air pollutant (66kg/ha/yr) removal by vegetation in England (ONS 2019[6]). In 2015 the coastal corridor and its immediate surrounding area potentially removed an estimated 6,279,357 kg of air pollutants (including ammonia, nitrogen dioxide, ozone, PM10, PM2.5, sulphur dioxide). The coastal corridor, and its immediate surrounding areas, is responsible for the removal of an estimated 25% of all air pollutants removed by vegetation in Cornwall.
  - Regulating Services - Freshwater Quality Improvement Potential: Cornwall faces a number of significant water quality issues as a result of historic mining activities, industry, development and agricultural practices. The potential of natural capital assets in the coastal corridor to regulate water quality is relatively low in terms of area, just 2332 ha are scored as having any capacity to deliver water quality benefits, equating to just 3.5% of the coastal corridor (Mosedale et al. 2019 in prep). Although the majority (49%) of this area only has a low capacity to deliver benefits, some 288ha do have a medium-high or high potential to deliver benefits (Mosedale et al. 2019 in prep). In particular, wetland areas in the coastal corridor are also likely to play a significant role in water quality regulation through denitrification, nitrification and mineralisation of pollutants.
  - Regulating Services - Bathing Water Quality Improvement: Bathing water quality influences the potential for recreational use. Much like freshwater quality, natural capital assets can help to improve bathing water quality by reducing pollution from surface and ground waters. There is also an increasing body of evidence that sand dunes and shingle can also help to reduce diffuse pollution in the marine environment with positive outcomes on bathing water quality. 19% of the coastal corridor was found to have some capacity to deliver benefits for bathing water quality through land use or management changes, equating to around 12,662 ha. The majority of this area (50%) only had a low potential to deliver benefits with just 11% having the potential to deliver medium high to high benefits, some 1382 ha.
  - Regulating Services - Flood Mitigation Potential: The UK NEA (2011) identifies coastal margins as playing an important role in storing and slowing the flow of surface water runoff. However, the overall capacity of the coastal corridor to mitigate flood risk is much less than in the rest of Cornwall, and the majority of natural capital assets with high flood mitigation potential are around NW and central Cornwall (Mosedale et al. 2019 in press). Some 29,808 ha of the coastal corridor still has some potential capacity to deliver flood mitigation benefits, almost 45% of the coastal corridor. The vast majority of this area (93%) only has a low potential to deliver flood mitigation benefits (Mosedale et al. 2019 in press). Only 132 ha of the coastal corridor have 'high' potential to deliver flood mitigation benefits.
  - Provisioning Services - Water Supply Potential: The coastal corridor has some significance for ground water source protection, around 328ha of the coastal corridor is classed as a ground water source protection zone which equates to 16% of Cornwall's total ground water source protection zone.

[6] https://www.ons.gov.uk/economy/environmentalaccounts/articles/ukairpollutionremovalhowmuchpollutiondoesvegetationremoveinyourarea/2018-07-30

- Supporting Services - Pollination Services Potential: The CEH Nectar plant diversity map for bees (Maskell et al. 2016[7]) suggests that the coastal corridor has a slightly higher mean value of nectar plant diversity for bees than the average for the whole of Cornwall. Casalegno et al. (2014[8]) also show that the coastal corridor has a slightly higher average habitat availability for pollinators than the rest of Cornwall, with a 5% lower amount habitat with 'low potential' to provide pollinator habitats and a 5% greater coverage of habitats with 'medium potential' to provide pollinator habitats. The distribution of habitat availability for pollinators shows high concentration around the NW coast of Cornwall particularly around West Penwith, Godrevy and Holywell (Casalegno et al. 2014). The coastal corridor notably contains 81.4% of the highest nectar productivity habitat, calcareous grassland, which is concentrated in one site in the coastal corridor, Holywell.
- Supporting Services - Species Diversity: The coastal corridor is a significant reserve of some of our most protected sites for biodiversity, containing some 74 Sites of Special Scientific Interest (SSSI), which cover some 8.2% of the area of the coastal corridor [5927 ha] and represent 29.4% of total area designated as SSSIs across Cornwall. Some 13,566 ha of the coastal corridor are covered by UK Biodiversity Action Plan priority habitats, 21% of the total area of the corridor and 27% of the total BAP habitat area in Cornwall. In comparison, BAP habitats cover only 14% of the total area of Cornwall. The coastal corridor is particularly important for: saltmarsh (82% of total area in Cornwall): sand dunes (85%), maritime cliffs and slopes (98%), reedbeds (91%), saline lagoons (90%), good quality semi-improved grassland habitats (69%), lowland calcareous grassland habitat (78%), lowland dry acid grassland (59%), lowland meadows habitat (45%), and traditional orchard habitat (37%).
- Cultural Services – Opportunities for Recreation: Greenspaces, paths and beaches (see footnotes for full list[9]) within the coastal corridor are predicted to receive approximately 18.64 million recreational day visits by English adult residents per year, with an associated annual welfare benefit to residents of £74 million (Day and Smith 2018[10]). The coastal corridor alone accounts for 49% of the total predicted recreational visits by adults to greenspace in Cornwall, and 51% of the total welfare benefit to residents in Cornwall (Day and Smith 2018).
- Cultural Services – Aesthetics: All 39 hotspots of high aesthetic value mapped by Casalegno et al. (2013[11]) are located in the coastal corridor. 65% of the coastal corridor is designated for its landscape value as an Area of Outstanding Natural Beauty (AONB) (41,901 ha), and this equates to 40% of the total area designated as an AONB across Cornwall.
- Cultural Services - Heritage: Despite representing just 17% of the land area of Cornwall, the coastal corridor was found to contain the majority (54%) of Cornwall's conservation areas. More than a third of the 145 conservation areas are coastal towns and villages, and 40% of Cornwall's registered parks and gardens occur directly along the south coast. The corridor also contains an estimated 15% of all scheduled monuments and 49% of listed buildings, and 16% of the Cornish world heritage site. Heritage coast designations cover 31%, some 20,577 ha, of the coastal corridor.
- Cultural Services – Health and wellbeing - Populations living near the coast in England are healthier than those inland (Wheeler et al., 2012) and longitudinal data suggest that individuals are healthier during periods when they live closer to the coast (White et al., 2013). The link between living near the coast and good health was also found to be strongest in the most economically deprived communities, suggesting that access to coastal environment can have a role in reducing health inequalities between the wealthiest and poorest members of society (Wheller et al. 2012, White et al. 2013).

[7] Maskell et al. (2016) Bee nectar plant diversity of Great Britain. NERC Environmental Information Data Centre. http://doi.org/10.5285/623a38dd66e8-42e2-b49f-65a15d63beb5

[8] Casalegno et al. (2014) Regional scale prioritisation for key ecosystem services, renewable energy production and urban development. PLoS ONE 9(9): e107822. https://doi.org/10.1371/journal.pone.0107822

[9] ORVal Includes country parks, amenity parks, recreation grounds, village greens, golf courses, gardens, woods, amenity woods, allotments, cemeteries, grave yards.

[10] Day and Smith (2018) Outdoor Recreation Valuation (ORVal) User Guide: Version 2.0, Land, Environment, Economics and Policy (LEEP) Institute, Business School, University of Exeter.

[11] Casalegno et al. (2013) Spatial covariance between aesthetic value & other ecosystem services. PLoS ONE 8(6): e68437. https://doi.org/10.1371/journal.pone.0068437.

Contents

ABBREVIATIONS

AES:	Agri-Environment Schemes
AONB:	Area of Outstanding Natural Beauty
BPS:	Basic Payment Scheme
CEH:	Centre for Ecology and Hydrology
CUA:	Cornwall Unitary Authority
DEFRA:	Department for Environment, Food and Rural Affairs
FBI:	Farm Business Income
MHW:	Mean High Water
NE:	Natural England
NT:	National Trust
ONS:	Office of National Statistics
OS:	Ordnance Survey
RSPB:	Royal Society for the Protection of Birds
SAC:	Special Area for Conservation
SPA:	Special Protection Area
SSSI:	Site of Special Scientific Interest
SWEEP:	South West Economic and Environmental Partnership

1. INTRODUCTION

The One Coast initiative aims to establish a nature-rich accessible corridor around the South West Coast for people and wildlife. The coastal corridor is defined as the continuous strip of land stretching from mean high water to 1km inland along the coastline. To assist the National Trust and RSPB (hereafter referred to as the project partners) to realise the ambitions of the One Coast project, the SWEEP One Coast project has collated an evidence base outlining some of the key economic, social and environmental characteristics of the section of the coastal corridor within Cornwall Unitary Authority (CUA). The Cornish section of the SW coastal corridor equates to 36% of the SW coastal corridor, by far the largest section when compared with other Local Authorities (LA), e.g. North Devon (6%) and South Hampshire District (12%). In order to explore the economic, social and environmental characteristics and significance of the coastal corridor the evidence base uses existing national and local data sets and official national statistics.

For the purposes of this report, the evidence base has been organised into three main sections: (1) socio-economic and demographic characteristics, (2) economic characteristics, and (3) environmental characteristics and composition [including a natural capital asset review]. Much of the evidence base for the One Coast project has been produced from spatial derived national environmental and economic datasets, for example, the Centre for Ecology and Hydrology's Land Cover Map 2015 and the 2011 Census Data, clipped or adjusted via best-fit methods to the coastal corridor. A brief methodology for each indicator/data set is outlined at the start of each section, or within each subsection.

It is envisaged that this information will be used by the project partners for a range of purposes.

- To communicate the significance of the coastal corridor from a variety of different perspectives.
- To highlight the capacity of the coastal corridor to provide multiple potential ecosystem service flows and benefits for society and the economy.
- To identify priority locations or focal points for investment based on the delivery of multiple or specific ecosystem services.
- To identify ecosystem goods and services that could be improved or are at risk, which could be used as a trigger for the development of Payments for Ecosystem Services type schemes. Where information on the natural capital assets can be combined with information on business locations this could be a powerful tool to trigger investment or the motivation for the development of Payments for Ecosystem Services type schemes.
- To help justify land management changes/decisions based on trade-offs between different ecosystem service flows.
- To help identify opportunities to operate alternative and innovative finance mechanisms for the One Coast project.

1.1 Cornwall's Coastal Corridor

Cornwall has the longest coastline of any county in England and its peninsula geography means that no inland area is more than 32 km from the sea. Although notoriously difficult to estimate, the Cornish coastline is most often estimated to be around 697km (422 miles) long but could be up to 1086km in length (OS 2017[12]). For the purpose of this review, the Cornish coastal corridor is defined as the continuous strip of land stretching 1km inland from mean high water. In general, Cornwall has an overwhelmingly rural character with two-thirds of the population living in rural areas. However, its polycentric urban form means that although Cornwall has a relatively sparse overall population density the coastal corridor is interspersed with multiple dense coastal settlements (e.g. St Austell, Truro, Falmouth, Bude, Newquay, Saltash and Penzance). The concentration of urban settlements in the coastal corridor makes it a focal point for much of Cornwall's economic activity and population.

Cornwall's coastal corridor is composed of an extensive range of natural features, including granite cliffs, small rocky coves and headlands, mudflats, sand dunes, sandy beaches and estuaries alongside wooded valleys, grazing pastures and arable lands. The South and North sections of the coast have distinctly different landscape and biodiversity characteristics. The South coast, on the English channel, consists of sheltered beaches, sandy coves and bays, deep water harbours, hills rolling down to the shoreline, tree-lined sheltered river estuaries and harbour towns. Lowland stretches are also to be found, sometimes backed by large expanses of dunes (or towans), such as near Par. The north coast is much more exposed to the prevailing winds associated with low-pressure weather conditions which move in from the Atlantic Ocean, with sheer cliffs, steep valleys and dunes, interspersed with large wide bays. There are a variety of habitats along the coastal corridor, including farmland, woodland, heathland, moorland and former

[12] *OS (2017) https://www.ordnancesurvey.co.uk/blog/2017/01/english-county-longest-coastline/*

mining sites, supporting a wealth of wildlife species. Cornwall's marine and coastal habitats provide a range of ecosystem services of significant economic and cultural value to Cornish residents and visitors, including food production, climate regulation, pollution control, coastal protection, energy production and improving mental and physical health and well-being.

The vast majority of the coastline is designated through a variety of different designation types, including SSSI, AONB and SAC, and many of these designations spill into the coastal corridor. Of the twelve separate areas that make up the Cornwall Area of Outstanding Natural Beauty (AONB), eleven cover sections of the Cornish coastline, including the Fal, Helford, Fowey and Camel estuaries. Cornwall also has six Voluntary Marine Conservation Areas (VMCAs) [e.g. Polzeath, St Agnes, Isles of Scilly, Helford, Fowey and Looe] which provide an additional focus for coastal and marine habitat protection, public awareness and engagement. The coastal corridor is also a centre for recreation with some 163 amenity beaches and contains almost 47% of the whole length of the SW coast path.

1.2 Natural Capital

Natural Capital can be broadly understood as the elements or assets of the natural environment which provide valuable ecosystem goods and services to people, or as defined by the Natural Capital Committee (2013:11[13]) *"those elements of nature which either directly provide benefits or underpin human wellbeing"*. The UK Natural Capital Committee defines natural capital as the "*stock of waters, land, air, species, minerals, and oceans. This stock underpins the economy by producing value for people, both directly and indirectly. Goods provided by natural capital include clean air and water, food, energy, wildlife, recreation, and protection from hazards*" (Natural Capital Committee 2019[14]). Natural capital assets can include species (including genetic variation), ecological communities, soils, freshwaters, land, minerals, the atmosphere, subsoil assets, and coasts and oceans (National Capital Committee 2013; Mace et al. 2015[15]). Under a natural capital framework, assets provide ongoing benefits critical to people's health and wellbeing, and to a sustainable economy (National Capital Committee 2013). Natural capital is by no means a simple concept but refers to the complex configuration of natural resources and ecological processes which together can contribute to human welfare. One example of a natural capital asset is woodland from which flows a variety of potential benefits, including fibre, flood risk reduction and carbon capture. Flows of benefits from natural capital assets are more commonly referred to as ecosystem goods and services.

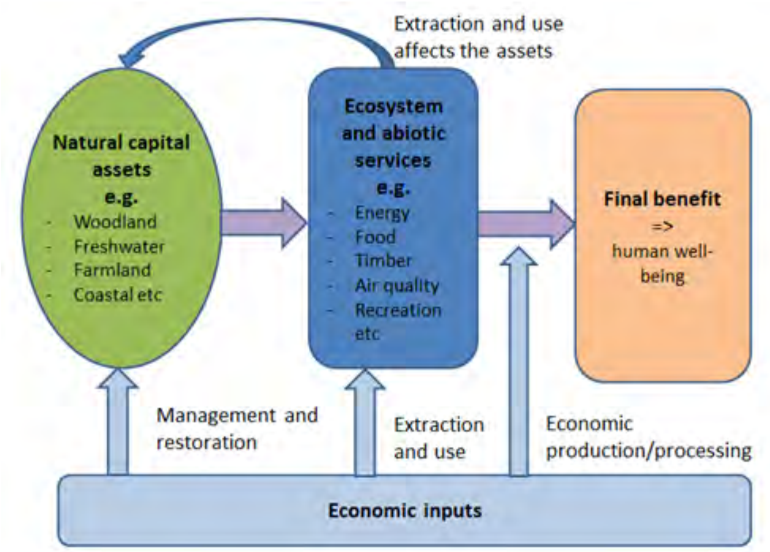


Figure 1. The link between assets, services and final benefits, (Source: Department for Environment, Food and Rural Affairs (Defra), Office for National Statistics)

[13] *Natural Capital Committee (2013)* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/516707/ncc-state-natural-capital-first-report.pdf
[14] *Natural Capital Committee (2019)* http://www.naturalcapitalcommittee.org/natural-capital/
[15] *Mace et al. (2015) Towards a risk register for natural capital, Journal of Applied Ecology, 52: 641-653.* https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/1365-2664.12431

2. SOCIO-ECONOMIC AND DEMOGRAPHIC CHARACTERISTICS

This section outlines the socio-economic and demographic characteristics of the people living in the coastal corridor (usual residents). Demographic indicators provide information on the number of people living in the coastal corridor (population size), the structure of this population (percentage of the population in different age ranges), how/where people live within the corridor (population density) and the population status or dynamism (immigration/out-migration, population growth rate). Socio-economic indicators provide an impression of economic progress and social change. For the coastal corridor, socio-economic indicators are used to provide a picture of not only the economic activities of the usual residents of the coastal corridor (e.g. labour force participation rates, unemployment rates) but also their state of wellbeing (general health) and quality of life (index of multiple deprivation, income per household). Together these indicators provide a picture of the socio-economic context within which any planned environmental changes and investment will play out. Furthermore, these indicators can aid the project partners to understand the number of people who could be influenced by investment, the beneficiaries of ecosystem goods and services, and where investments could be targeted in relation to different aspects of the population structure and quality of life.

2.01 Population Size

- *Using best-fit methods and ONS 2011 Census data[16], 32%-37% of the total population of Cornwall is estimated to be resident within the coastal corridor, equating to between 169,181 to 197,142 usual residents (ONS 2011).*
- *Using Census Output Areas (OAs[17]), 48% of Cornwall's population is thought to reside in output areas which intersect with the coastal corridor (ONS 2011). In comparison, only 28% of the regional population of the SW reside in OAs which intersect with the coastal corridor.*
- *The population of the coastal corridor is relatively dispersed. 42% of the population of the coastal corridor reside in urban areas and 58% in rural areas.*

Cornwall has an estimated resident population of 549,404 (Cornwall Council 2017[18]). Estimation of the population of the coastal corridor was made using the Office of National Statistics (ONS) National Census data (ONS 2011). The coastal corridor is not an official statistical geography, for example, a census output area (OA) or Lower Super Output Area (LSOA), parish, ward or county. Consequently 'best fit' methods had to be used to estimate the resident population. Estimates were also made using the CEH UK gridded population 2011, based on Census 2011 and Land Cover Map 2015 spatial dataset (Reis et al. 2017[19]). The CEH UK gridded population 2011 provides a population estimate for 1km^2 cells for the whole of the UK based on 2011 census data. The cells intersecting the coastal corridor were extracted, and population estimates were adjusted for the proportion of the grid cell which intersected with the coastal corridor. Based on the CEH UK gridded population dataset the coastal corridor had a population in 2011 of 169,181, this represents 32% of the total population of Cornwall in 2011.

Using the ONS OA dataset (adjusted to the coastal corridor using the proportional best fit method outlined above for the UK gridded population dataset) provides a population estimate of 197,142, 36.7% of the total population of Cornwall in 2011. Extending the area to cover all 2011 census Output Areas (OA[20]) which intersect with the coastal corridor (see Map.1) suggests that the coastal corridor and its immediately surrounding areas has an approximate population of 258,400, which equates to 48% of the total population of Cornwall in 2011.

OAs are defined by the ONS as urban if they have a population of 10,000 or more[21]. Using the ONS rural-urban classification suggests that the coastal corridor has an urban population of 84,294 which equates to 42% of the population of the coastal corridor. In comparison, 86% of Cornwall's population is classified as rural. Discounting urban areas, the coastal corridor still contains an estimated 21% of the Cornish population.

---

[16] *Office for National Statistics; National Records of Scotland ; Northern Ireland Statistics and Research Agency (2016): 2011 Census data. UK Data Service (Edition: June 2016). DOI: http://dx.doi.org/10.5257/census/aggregate-2011-1. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3].*

[17] *Office for National Statistics, 2011 Census: Digitised Boundary Data (England and Wales) [computer file]. UK Data Service Census Support. Downloaded from: https://borders.ukdataservice.ac.uk/. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3].*

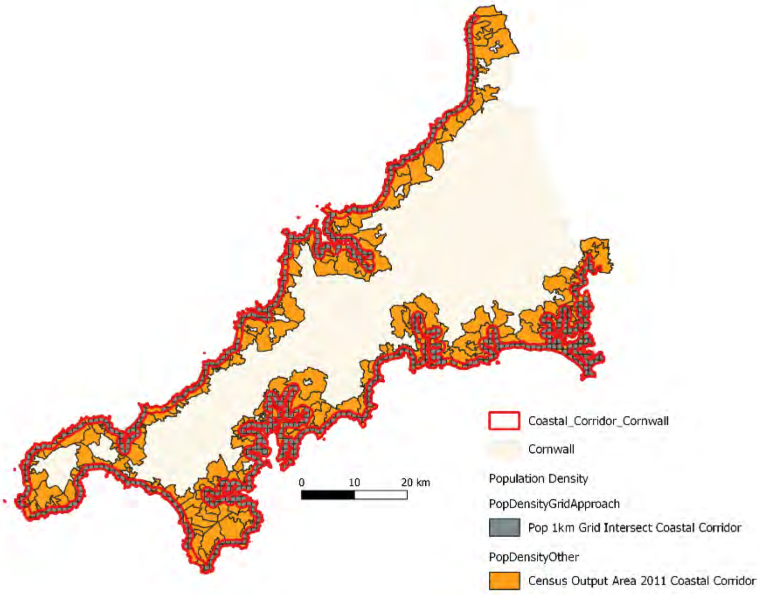
[18] *Cornwall Council (2017) https://www.cornwall.gov.uk/council-and-democracy/data-and-research/data-by-topic/population/*

[19] *Reis et al. (2017) UK gridded population 2011 based on Census 2011 and Land Cover Map 2015. NERC Environmental Information Data Centre. https://doi.org/10.5285/0995e94d-6d42-40c1-8ed4-5090d82471e1https://catalogue.ceh.ac.uk/documents/0995e94d-6d42-40c1-8ed4-5090d82471e1*

[20] *ONS (2011) https://www.ons.gov.uk/methodology/geography/ukgeographies/censusgeography*

[21] *ONS (2011) Rural-urban classification - https://www.ons.gov.uk/methodology/geography/geographicalproducts/ruralurbanclassifications/2011ruralurbanclassification*

Map 1. Areas used to estimate the population of the coastal corridor (Source: ONS 2011[22] and Reis et al 2017[23])



Map 1. Areas used to estimate the population of the coastal corridor (Source: ONS 2011[22] and Reis et al 2017[23])

2.02 Population Density

➢ *The coastal corridor has a population density more than twice that of the rest of Cornwall.*

Cornwall is one of England's most dispersed counties, largely consisting of suburban/edge-land with little truly rural space. However, many of Cornwall's largest urban areas, towns and villages are concentrated around the coast and estuarine areas. This concentration of people around the coastal corridor is reflected in the higher population density of the coastal corridor. Based on the ONS OA Census data (2011), the coastal corridor has an average population density of 3.04 usual residents per ha, more than twice the population density of the rest of Cornwall, 1.14 usual residents per ha. The coastal corridor has a maximum population density of 58.1 usual residents per ha compared to the rest of Cornwall with a maximum population density of 45.1 usual residents per ha.

	Coastal Corridor	Rest of Cornwall	Cornwall
All Usual Residents (ONS OA 2011 Census)	197,142	338,858	536,000
Area (ha)	64,814	296,530	361,344
Population density (usual residents per ha)	3.04	1.14	1.48

Table 1. Population density of the coastal corridor (ONS 2011)

2.03 Population Growth

➢ *Population predictions for the whole of Cornwall suggest that the coastal corridor could see a 9.15% increase in population levels by 2030, an increase from 197,142 usual residents in 2011 to 220,578 by 2030.*

➢ *By 2030 the population density of the coastal corridor could rise from 3.04 usual residents per ha to 3.4 usual residents per ha.*

Cornwall's population has been growing steadily since the 1960s and has consistently grown quicker than the rest of the South West (SW) and is one of the fastest growing areas in the UK (Cornwall Council 2011[24]). Population projections are made by the ONS based on assumptions about past and future levels of fertility, mortality and migration[25]. They should be used with caution as they rely on assumptions and can be affected by difficult to predict phenomena, such as economic recessions. Therefore, the use of

---

[22] *Office for National Statistics; National Records of Scotland ; Northern Ireland Statistics and Research Agency (2016): 2011 Census data. UK Data Service (Edition: June 2016). DOI: http://dx.doi.org/10.5257/census/aggregate-2011-1. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3].*

[22] *Office for National Statistics, 2011 Census: Digitised Boundary Data (England and Wales) [computer file]. UK Data Service Census Support. Downloaded from: https://borders.ukdataservice.ac.uk/. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3].*

[23] *Reis et al. (2017) UK gridded population 2011 based on Census 2011 and Land Cover Map 2015. NERC Environmental Information Data Centre. https://doi.org/10.5285/0995e94d-6d42-40c1-8ed4-5090d82471ehttps://catalogue.ceh.ac.uk/documents/0995e94d-6d42-40c1-8ed4-5090d82471e1*

[24] *Cornwall Council (2011) 2011 Census at a glance, Available at: https://www.cornwall.gov.uk/media/3624040/Census_at_a_glance_1stRelease.pdf*

[25] *https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections*

population projection figures should be treated as a guide to what the future population trends and levels might look like, if past trends continue.

The ONS projects national and subnational population trends every two years[26]. Much like the rest of England, the population of Cornwall is predicted to grow over the next few decades (Cornwall Council 2011, 2013[27]). Past trends suggest that the population in Cornwall grows by on average 3,850 persons per year (Cornwall Council 2013). Simple extrapolation of past trends suggests that Cornwall's population could reach 607,154 by 2030, a 10.5% increase on 2015 population levels. However, more detailed annual population projections, released by the ONS in 2016, suggest that Cornwall's population will reach 605,892 by 2030, a 9.15% increase from 2015 levels, and 630,285 by 2040, a 13.5% increase on 2015 population levels (Cornwall Council 2018[28]). It must be noted that estimates vary depending on the data available and the use of national or local data (Cornwall Council 2014[29]).

Applying Cornwall-wide population growth projections to the coastal corridor suggests that population levels, based on ONS 2011 Census data, could reach 220,500 by 2030 and 229,400 by 2040[30]. Subnational analysis suggests that the main driver of population growth in Cornwall is migration, specifically in-migration for economic and lifestyle reasons. The growth of the higher education sector and improved employment prospects are both factors thought to have driven recent population expansion (Cornwall Council 2013).

2.04 Population Structure

- *Usual residents of the coastal corridor and its immediate surrounding area have a slightly higher mean age and median age compared to the rest of Cornwall.*
- *The age differential across Cornwall is predicted to grow, with 31% of the population predicted to be 65 or over by 2030*.

Demographic structures vary at the local level. Alongside an increase in overall population levels in the coastal corridor, population projections suggest that there is also likely to be an increasingly older population (Cornwall Council 2013, 2014 and 2016). Population projections by age group suggest that broadly speaking in Cornwall there will be a "*similar proportion of younger aged people, a lower proportion of working age people and a higher proportion of older people in the population by 2030*" (Cornwall Council 2013). Although an ageing population reflects national trends, the predicted dependency ratio (the ratio of working age people supporting younger and older groups of the population) is higher in Cornwall than for the whole of the SW. In 2010, every 100 people of working age in Cornwall were supporting 60 young/pension age people, in comparison to a ratio of 100:56.5 for the whole of the SW. By 2030 the dependency ratio for Cornwall is predicted to reach 100:78.8 compared to 100:74.4 for the whole SW (Cornwall Council 2018[31]). A higher dependency ratio means more people not working or paying taxes, and more people in need of care (Cornwall Council 2013, 2018).

Mean age and average for the coastal corridor were estimated using ONS 2011 Census dataset for Output Areas (OAs). It was not possible to extract data specifically for the coastal corridor, or use best-fit methods, instead OAs which intersected or lie within the coastal corridor were used to estimate mean and median age for the coastal corridor, and all other OAs were used to estimate mean and median age for the 'rest of Cornwall'. This approach is acknowledged to be limited, as the population used to estimate mean age and the median age for the coastal corridor, 240,737, is notably higher than the estimated population outlined in Section 2.01 and includes residents who live close to but outside of the coastal corridor.

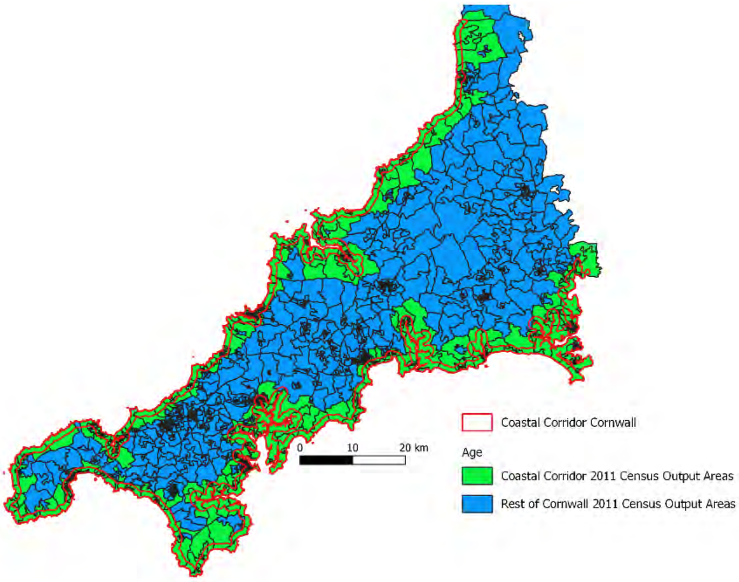
The Census 2011 OAs data suggest that the coastal corridor is likely to have a slightly higher percentage of its population aged between 45-64 than the rest of Cornwall (+0.5%) and a slightly higher proportion of its population aged over 65+ (+3.5%). In terms of overall population age, OA intersecting or within the coastal corridor have a higher mean age (+2.5 years) and median age (+2.9 years) compared to the rest of Cornwall. The higher population over 45 and over 65 is not unexpected, looking at the national picture shows that populations with the highest median age are often concentrated in coastal areas, national parks, and the SW (ONS, 2018). In terms of projected population growth, 31% of the population is predicted to be 65 or over in Cornwall by 2030.

---

[26] *ONS – Population projections https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections*
[27] *https://www.cornwall.gov.uk/media/3642933/BN3-Population-v3-Nov-13.pdf*
[28] *Cornwall Council (2018) https://www.cornwall.gov.uk/health-and-social-care/public-health-cornwall/joint-strategic-needs-assessment-jsna/data-maps-and-infographics/tab-placeholder-hidden/data/population-projections/*
[29] *Cornwall Council (2014) https://www.cornwall.gov.uk/media/22243248/2014-based-local-population-projections_pyramids.pdf*
[30] *For the Coastal Corridor the 2011 census estimates were first adjusted to 2015 levels using the recorded changes in Cornwall's overall population levels between 2011 and 2015 recorded by Cornwall Council as a 2.5% increase. ONS population projections were then applied.*
[31] *https://www.cornwall.gov.uk/health-and-social-care/public-health-cornwall/joint-strategic-needs-assessment-jsna/data-maps-and-infographics/tab-placeholder-hidden/data/population-projections/*

Age	Coastal Corridor	Rest of Cornwall
Under 15	15.7%	17.8%
16 to 24	9.8%	10.2%
25 to 44	21.7%	23.1%
45 to 64	29.2%	28.7%
Over 65	23.7%	20.0%
Mean Age	44.7	42.2
Median Age	46.7	43.8

Table 2. Age profile of Census 2011 Output Areas intersecting or within the coastal corridor and those in the Rest of Cornwall (Source: ONS 2011 and Reis et al 2017)



Map 2. 2011 ONS Census Output Areas classed as the coastal corridor (green) and classed as the Rest of Cornwall (Blue)

2.05 Population Health

- *Populations living near the coast in England are generally thought to be healthier than those inland (Wheeler et al., 2012[32]) and longitudinal national data suggest that individuals are healthier during periods when they live closer to the coast (White et al., 2013[33]).*
- *In the coastal corridor, 78.6% of usual residents report good or very good health, which is slightly lower than the rest of Cornwall where 79.1% report good or very good health (ONS 2011).*
- *The ageing population in Cornwall set out in Section 2.04, is likely to reduce population health in the future and place a higher demand on services such as health and care provision.*

Health is closely related to productivity and economic prosperity, and social wellbeing and the wealth of communities. The 2011 ONS Census dataset also provides an indication of the general wellbeing and health of the population. Health and wellbeing is self-assessed, based on the individual's perception and therefore provides only a general indicator of wellbeing and health-related quality of life. In England over 81.2% of people reported their general health as either very good or good (ONS 2013[34]). To estimate the general health of residents of the coastal corridor the ONS 2011 Census OA dataset was used, adjusted using best-fit methods to the coastal corridor and the rest of Cornwall. Estimates suggest very little difference between the self-reported health of usual

[32] Wheeler et al. (2012) Does living by the coat improve health and wellbeing? Health Place 18(5): 1198-1201. oi: 10.1016/j.healthplace.2012.06.015
[33] White et al. (2014) Coastal proximity and physical activity: Is the coast an under-appreciated public health resource? Preventive Medicine 69: 135-140. https://doi.org/10.1016/j.ypmed.2014.09.016
[34] ONS https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/healthandwellbeing/articles/generalhealthinenglandandwales/2013-01-30

residents within the coastal corridor and in the rest of Cornwall (Table 3). Within the coastal corridor, 78.6% of usual residents report good or very good health which is slightly lower than the rest of Cornwall where 79.1% report good or very good health.

General Health	Coastal Corridor	Rest of Cornwall	Cornwall
Very Good	44.9%	45.5%	45.3%
Good	33.7%	33.6%	33.6%
Fair	15.1%	14.7%	14.8%
Bad	4.9%	4.8%	4.9%
Very Bad	1.4%	1.4%	1.4%

Table 3. Self-Reported Health for the Coastal Corridor and Rest of Cornwall (Source: ONS 2011)

Broadly, the 2011 ONS census figures suggest that an increasing percentage of Cornwall's population identify their health as good compared to 2001 levels (Whittaker 2017[35]). However, the ageing population in Cornwall, set out in Section 2.04, is likely to affect these figures in the future. Available health data suggest that Cornwall has higher levels of obesity in adults, incidence of malignant melanoma, hospital stays for self-harm and alcohol-related harm. Priorities in Cornwall include reducing smoking, physical inactivity, unhealthy diets, excess alcohol and lack of social connections. Whittaker (2017) found that for elective hospital admissions, such as a hip replacement, the ratio in Cornwall is 140 (any figure above 100 is a higher proportion of admissions than had been expected), compared to a 123 in the SW. This may reflect Cornwall's high ageing population and thus a higher demand on services such as healthcare provision. Furthermore, 25% of children and adults are classified as obese in Cornwall, compared with 24.7% in the SW and 24.1% in England. Finally, the ageing population and proportionally higher numbers of older people in Cornwall, in addition to a swell of tourists throughout the year, puts an extremely high demand on the NHS, utility services and infrastructures (Whittaker 2017).

2.06 Residential Property Prices

- *Average residential property price within the coastal corridor was estimated to be around £336 thousand pounds, 27% higher than the average for the whole of Cornwall.*

Residential property is generally the most valuable asset that people own. The significance of residential property prices means that these can provide a basic indicator of the socio-economic status of a location (Coffee et al 2013[36]). To estimate house prices within the coastal corridor, house price data were accessed through the HML Land Registry (2019) Price Paid dataset[37]. This provides purchase price data alongside postcodes. Average purchase prices were mapped against post-code boundaries (Pope 2017[38] [39]).

The average property price for residential property across the whole of Cornwall was found to be £264k. Average price per postcode was compared with the average residential property price for the whole of Cornwall. Postcodes overlapping with the coastal corridor had a higher than average residential price of £294k, 11.4% higher than the average for the whole of Cornwall. When weighted by area of each postcode intersecting with the coastal corridor the average residential property price within the coastal corridor was found to be £336k, 27% higher than the average for the whole of Cornwall.

---

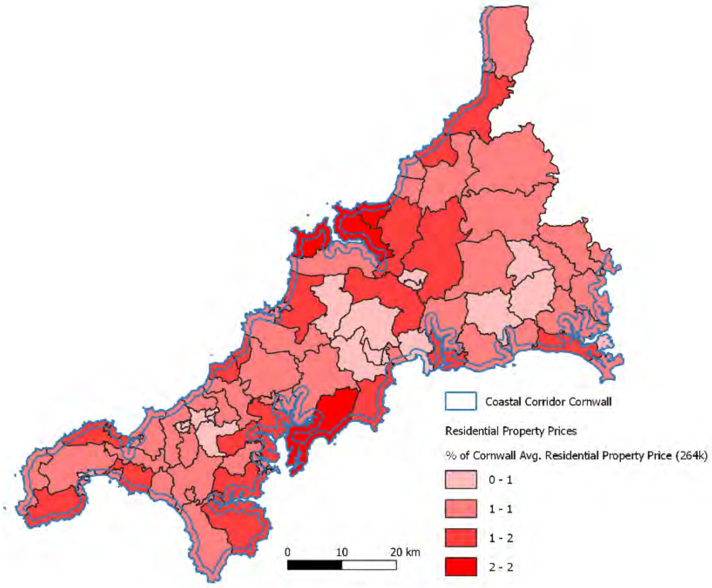
[35] *Whittaker L (2017) Cornwall's Vital Issues 2017, Cornwall Community Foundation, Available at: http://www.ukcommunityfoundations.org/wp-content/uploads/2017/10/Cornwalls-Vital-Issues-2017.pdf*

[36] *Coffee et al. (2013) Relatively residential property value as a socio-economic status indicator for health research, Int J Health Geography, 12: 22, 10.1186/1476-072X-12-22*

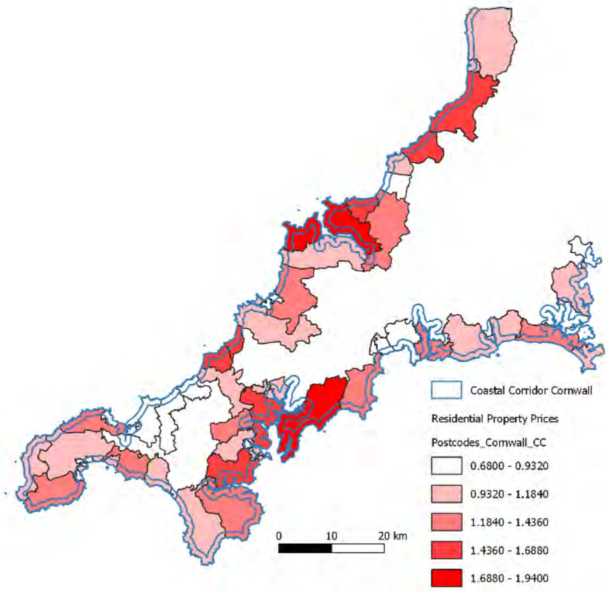
[37] *HM Land Registry (2019) Price Paid Dataset: https://www.gov.uk/government/statistical-data-sets/price-paid-data-downloads*

[38] *Pope (2017). GB Postcode Area, Sector, District, [Dataset]. University of Edinburgh. https://doi.org/10.7488/ds/1947.*

[39] *Contains Ordnance Survey data © Crown copyright and database right 2012 Contains Royal Mail data © Royal Mail copyright and database right 2012 Contains National Statistics data © Crown copyright and database right 2012. GIS vector data.*



Map 3. Residential property price data compared to the average for Cornwall (Source: HM Land Registry (2019) and Pope and Addy (2017))



Map 4. Residential property prices compared to the average for Cornwall for the coastal corridor (Source: HM Land Registry (2019) and Pope and Addy (2017))

2.07 Economically Active/Inactive

- *The coastal corridor contains a slightly lower percentage of economically active residents (-3%) than the rest of Cornwall (2011), and a higher percentage of economically inactive residents who are retired (+2%) or a full-time student (ONS 2011).*
- *90% of economically active usual residents of the coastal corridor are in employment, a very similar figure to the rest of Cornwall (91%) (ONS 2011)*
- *24% of economically active residents in employment in the coastal corridor are self-employed, 2% higher than for the rest of Cornwall and 10% higher than the national average (ONS 2011)*

The percentage of people in Cornwall and the Isles of Scilly employed and economically active is thought to be increasing at a faster rate than that seen in England. When compared to other LEP areas, Cornwall and the Isles of Scilly have the lowest proportion of full-time workers. Similarly, the male full-time employment proportion in Cornwall is significantly less than the England average and, again, the lowest of all the LEP areas.

The economic activity of usual residents within the coastal corridor and the rest of Cornwall are very similar, however, there are some minor variations (ONS 2011). A slightly lower percentage of usual residents in the coastal corridor are economically active (65%) compared to the rest of Cornwall (68%). Of those usual residents who are economically active in the coastal corridor 90% are in employment, 5.1% are economically active but unemployed and 4.7% are full-time students, this is a slightly higher amount of full-time students and a lower percentage unemployed than the rest of Cornwall (ONS 2011). Assessing economically active usual residents in employment shows that there is a slightly lower percentage in full-time employment than in the rest of Cornwall (-2%) and a slightly higher percentage that are self-employed (+2%).

The higher levels of self-employed economically active residents in the coastal corridor could reflect (a) strong demand for 'lifestyle' businesses; and (b) self-employment as a necessity, reflecting an absence of attractive employment options. High self-employment levels also pose challenges in relation to (1) the capacity of those individuals to benefit from training and development support, networking opportunities and business support processes; and, (2) how those entrepreneurs can be supported to become employers and run high growth businesses (Buckman and Southern 2015[40]). Self-employment is known to be particularly important in the agriculture, forestry and fishing industry (68% of workers are self-employed); construction (52%); arts, entertainment and recreation (36%); administrative support services (35%); and, professional, scientific and technical activities (34%) (Buckman and Southern 2015). Notably, self-employment was at its highest level in 40 years at the time of the 2011 Census (ONS 2011[41]).

Finally, in terms of unemployment, figures suggest that the coastal corridor is very similar to the rest of Cornwall. However, there is a slightly higher percentage of unemployed aged between 50-74; this is likely to be reflecting the older population indicated in section 2.04. Furthermore, there is a lower percentage of usual residents who have never worked (-2%) in the coastal corridor (ONS 2011).

	Coastal Corridor	%	Rest of Cornwall	%
All usual residents aged 16 to 74	143,001	37%	249,069	63%
Economically Active	93384	65%	168325	68%
Economically Inactive	49617	35%	80744	32%
Economically active	93384		168325	
In employment	84484	90%	153768	91%
In employment: Employee: Part-time	*21558*	*26%*	*38702*	*25%*
In employment: Employee: Full-time	*43002*	*51%*	*81063*	*53%*
In employment: Self-employed	*19925*	*24%*	*34003*	*22%*
Unemployed	4531	5.1%	8049	5.2%
Full-time student	4369	4.7%	6497	4.2%
Economically Inactive	49617		80744	
Retired	*28993*	*58%*	*45241*	*56%*
Student (including full-time students)	*6927*	*14%*	*9892*	*12%*
Looking after home or family	*5257*	*10%*	*10380*	*13%*
Long-term sick or disabled	*6060*	*12%*	*11006*	*14%*
Other	*2379*	*5%*	*4225*	*5%*
Unemployed	4531	3.2%	8060	3.2%
Unemployed: Age 16 to 24	*1354*	*30%*	*2498*	*31%*
Unemployed: Age 50 to 74	*1102*	*24%*	*1797*	*22%*
Unemployed: Never worked	*415*	*9%*	*869*	*11%*
Long-term unemployed	*1660*	*37%*	*2897*	*36%*

Table 4. Economic Activity of Usual Residents in Coastal Corridor and Rest of Cornwall (Source: ONS 2011)

2.08 Industry Employed-In

- *Wholesale, retail trade, repair, motor vehicle/cycles (15.9%); human health or social work (13.1%); accommodation or food services activities (11.6%); education (10.5%); and construction (8.4%) are the most important industries for the coastal corridor in terms of employment (ONS 2011).*

[40] Buckman and Southern (2015) https://www.cioslep.com/assets/uploads/documents/1469447094_Employment%20and%20Skills%20Strategy%20(new%20version).pdf
[41] https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/articles/transitionfromamanufacturingtoserviceledlabourmarketoverpast170years/2015-08-06

- *Notably, the coastal corridor has a higher percentage of usual residents active in accommodation and food services (+3.9%); education (+1.2%); transport and storage (+0.4%); professional, scientific and technical (+0.7%); information and communication industries (+0.4%); finance or insurance (+0.2%); and real estate (+0.3%) (ONS 2011).*
- *Existing key employment sectors are predicted to continue to provide the majority of employment in Cornwall in the foreseeable future (Buckman and Southern 2015).*

The 2011 Census (ONS 2011) captures both the economically active usual residents and the industry they are employed-in. Industry employed-in provides a snapshot of the labour market structure of usual residents of the coastal corridor and the rest of Cornwall. The Census 2011 dataset only provides information on usual residents aged between 16 and 74 in employment the week before the census in England and Wales by industry. The estimates are as at census day, 27th March 2011. Industries are coded using the UK Standard Industrial Classification of Economic Activities (UKSIC). To estimate the industry employed-in of usual residents of the coastal corridor the ONS 2011 Census OA dataset was used, adjusted using best-fit methods to the coastal corridor and the rest of Cornwall.

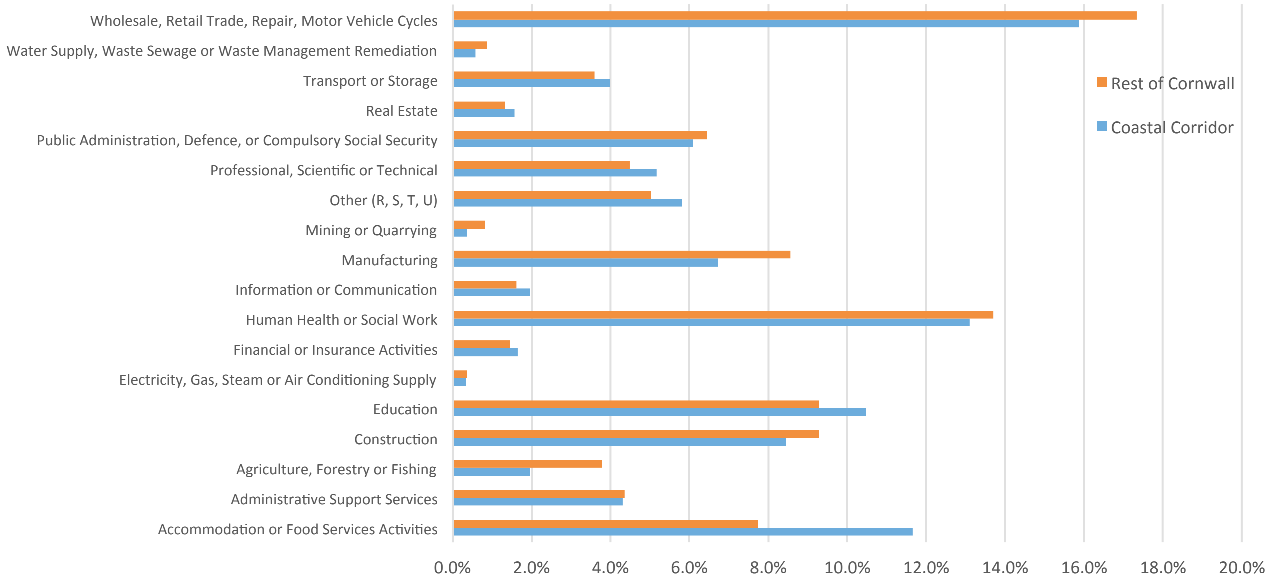
Table 5 and Graph 1 compare the percentage of usual residents by industry-employed in the coastal corridor with the rest of Cornwall. The most dominant industries, in terms of percentage of usual residents employed, include: wholesale, retail trade, repair, motor vehicle cycles (15.9%); human health or social work (13.1%); accommodation or food services activities (11.6%); education (10.5%); and construction (8.4%). The dominance of sectors such as 'wholesale, retail trade, repair and motor vehicles/cycles' and 'human health/social work' is not unexpected, these are linked to services sectors and tend to be the major employers everywhere. These service sectors are only likely to grow further with rising population levels and an increasingly ageing population in Cornwall, as older people have a greater likelihood of preference for services over goods (LEP 2012). In terms of Cornwall as a whole, looking at employment broken down by sector highlights the importance of retail; health and social care; education; hospitality; construction; manufacturing; and, public administration in total employment terms. A 2015 report by CIOSLEP (Buckman and Southern 2015) suggests that existing key employment sectors will continue to provide the majority of employment in the LEP area in the foreseeable future.[42]

Notably, the coastal corridor has a higher percentage of usual residents active in accommodation and food services (+3.9%); education (+1.2%); transport and storage (+0.4%); professional, scientific and technical (+0.7%); information and communication industries (+0.4%); finance or insurance (+0.2%); and real estate (+0.3%). There are higher percentages of usual residents employed in industries linked to tourism, e.g. accommodation and food services, transport and storage, and also those often associated with urban areas such as professional, scientific and technical, information and communication industries. There are notably lower percentages of usual residents employed in agriculture, forestry or fishing (-1.9%); manufacturing (-2.1%); and wholesale, retail trade, repair, motor vehicle cycles (-1.4%) industries. If urban areas are removed this shows a similar picture.

Industry Employed In	Coastal Corridor		Rest of Cornwall		Cornwall
	Count	%	Count	%	%
Agriculture, Forestry or Fishing	1713	1.9%	6018	3.8%	3.1%
Mining or Quarrying	315	0.4%	1290	0.8%	0.6%
Manufacturing	5917	6.7%	13589	8.6%	7.9%
Electricity, Gas, Steam or Air Conditioning Supply	286	0.3%	589	0.4%	0.4%
Water Supply, Waste Sewage or Waste Management Remediation	505	0.6%	1370	0.9%	0.8%
Construction	7422	8.4%	14761	9.3%	9.0%
Wholesale, Retail Trade, Repair, Motor Vehicle Cycles	13951	15.9%	27530	17.3%	16.8%
Transport or Storage	3504	4.0%	5713	3.6%	3.7%
Accommodation or Food Services Activities	10243	11.6%	12286	7.7%	9.1%
Information or Communication	1722	2.0%	2568	1.6%	1.7%
Financial or Insurance Activities	1444	1.6%	2301	1.4%	1.5%
Real Estate	1380	1.6%	2105	1.3%	1.4%
Professional, Scientific or Technical	4548	5.2%	7129	4.5%	4.7%
Administrative Support Services	3779	4.3%	6933	4.4%	4.3%
Public Administration, Defence, or Compulsory Social Security	5354	6.1%	10257	6.5%	6.3%
Education	9212	10.5%	14754	9.3%	9.7%
Human Health or Social Work	11517	13.1%	21769	13.7%	13.5%
Other (R, S, T, U)	5109	5.8%	7972	5.0%	5.3%
Industry: All categories	87920		158934		

Table 5. Usual residents by industry employed-in for the coastal corridor and the rest of Cornwall (Source: ONS 2011)

[42] *"Accommodation and food services" – with clear links to tourism – accounts for around 25,000 employee jobs in Cornwall & Isles of Scilly; compared to the national average, this is double the number that might typically be expected in an economy of this scale (2011).*



Graph 1. Usual residents by industry employed-in for the coastal corridor and the rest of Cornwall (Source: ONS 2011)

2.09 Occupation

➢ *There is a slightly higher percentage of usual residents of the coastal corridor who are employed as managers, directors and senior officers and in professional occupations (39%) compared to the rest of Cornwall (33%).*

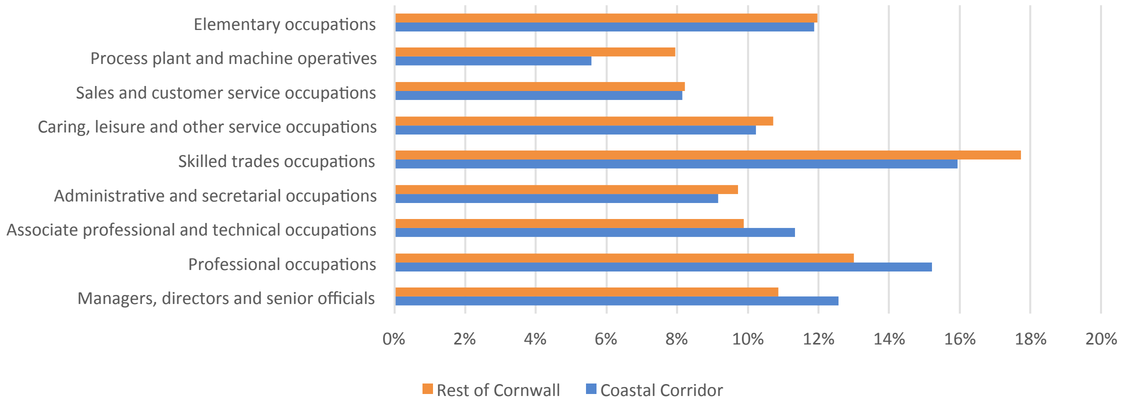
The 2011 Census captures the occupation of usual residents aged 16 to 74 in employment the week before the census (ONS 2011). A person's occupation provides an understanding of the workforce and type of skills available in an area, and is particularly useful in understanding local economic development, monitoring labour market trends[43]. Occupations are classified based on the Standard Occupational Classification 2010[44]. The ONS 2011 Census OA dataset was used to estimate the occupations of usual residents in the coastal corridor; data for OA was adjusted using best-fit methods to the coastal corridor and the rest of Cornwall.

Table 6 and Graph 2 compares the occupations of usual residents in the coastal corridor with the rest of Cornwall. The highest percentage occupations in the coastal corridor include skilled trades occupations (16%), professional occupations (15%), managers, directors and senior officials (13%) and elementary occupations (12%). Dominant occupations in the coastal corridor echo those for the rest of Cornwall, however, there are some notable differences. Professional occupations; managers, directors and senior officials; and associate professionals, account for 39% of the usual residents' occupations in the coastal corridor, compared to 33% in the rest of Cornwall. There are also notably lower levels of process plant and machine operatives and skilled trades occupations in the coastal corridor.

Occupation	Coastal Corridor		Rest of Cornwall		Cornwall
	Count	%	Count	%	%
Managers, directors and senior officials	11050.7	13%	17248	11%	10.9%
Professional occupations	13372.6	15%	20662	13%	13.8%
Associate professional and technical occupations;	9953.2	11%	15691	10%	11.2%
Administrative and secretarial occupations	8053.6	9%	15455	10%	8.8%
Skilled trades occupations	14010.4	16%	28158	18%	16.3%
Caring, leisure and other service occupations	8991.2	10%	17031	11%	10.6%
Sales and customer service occupations	7151.3	8%	13044	8%	7.5%
Process plant and machine operatives	4894.6	6%	12629	8%	5.9%
Elementary occupations	10442.3	12%	19018	12%	14.8%
All categories: Occupation	87919.7		158934		

Table 6. Occupation of usual residents in the coastal corridor and rest of Cornwall (Source: ONS 2011)

[43] *ONS - Occupation https://www.nomisweb.co.uk/census/2011/qs606uk*
[44] *More information about SOC2010 can be found here: http://www.ons.gov.uk/ons/guide-method/classifications/current-standard-classifications/soc2010/index.html*



Graph 2. Occupation of usual residents in the coastal corridor and rest of Cornwall (Source: ONS 2011)

2.10 Index of Multiple Deprivation

- *Six neighbourhoods which intersect the coastal corridor rank within the 10% most deprived Lower Super Output Areas (LSOAs) in England, out of a total of seventeen neighbourhoods which rank amongst the 10% most deprived in England across the whole of Cornwall (35%).*
- *Eight neighbourhoods which intersect the coastal corridor are within the 20% most deprived LSOAs in England, out of a total of twenty-seven neighbourhoods in Cornwall classed as amongst the 20% most deprived in England (30%).*

As of 2015, Cornwall as a whole is not deprived but there are neighbourhoods with consistently high levels of deprivation. Since 2004, the UK government has measured how deprived different neighbourhoods are compared to one another. The Index of Multiple Deprivation (IMD) is the official measure of relative deprivation for small areas (or neighbourhoods) in England[45]. Deprivation covers a broad range of issues and refers to unmet needs caused by a lack of resources of all kinds, not just financial. The Index measures deprivation in its broadest sense by assessing seven domains of deprivation: income, employment, health and disability, education, skills and training, barriers to housing and services, crime and the living environment. Indicator data is then combined to produce a single deprivation score for each area, which allows different areas across England to be ranked relative to each other according to their level of deprivation. Every neighbourhood in England is ranked, resulting in a ranking from 1 (most deprived area) to 32,844 (least deprived area). Deprivation is then measured generally in terms of whether a neighbourhood falls into the most deprived 10% or 20% of rankings. The ranked approach means that how deprived an area is depends on everywhere else. 2015 data show that Cornwall is now ranked 143 out of 326 local authority areas for deprivation (where 1 is having the highest proportion of the population living in the most deprived neighbourhoods). Whereas in 2010 Cornwall ranked 154 out of the 326 local authority areas for deprivation.

IMD is mapped spatially at the LSOA geography by the ONS[46]. The ONS class LSOAs as neighbourhoods, each LSOA contains roughly 1500 people but can be very different in terms of their actual size. There are 32,844 LSOAs across England. The IMD decile is calculated by ranking all 32,844 LSOA and then dividing them into 10 equal groups. Group 1 is the 10% most deprived LSOAs in the UK, whilst LSOAs in group 10 are the 10% least deprived areas in the UK[47]. Estimations of deprivation levels in relation to the Coastal Corridor were made using the English Indices of deprivation 2015 dataset (Ministry of Housing, Communities and Local Government 2015[48]). All LSOAs intersecting the coastal corridor were selected and analysed; it was not possible to use best-fit methods.

Six neighbourhoods which intersect the coastal corridor are within the 10% most deprived LSOAs in England, out of a total of seventeen across the whole of Cornwall (35%). Eight neighbourhoods which intersect the coastal corridor are within the 20% most deprived LSOAs in England, out of a total of twenty-seven neighbourhoods in Cornwall classed as amongst the 20% most deprived

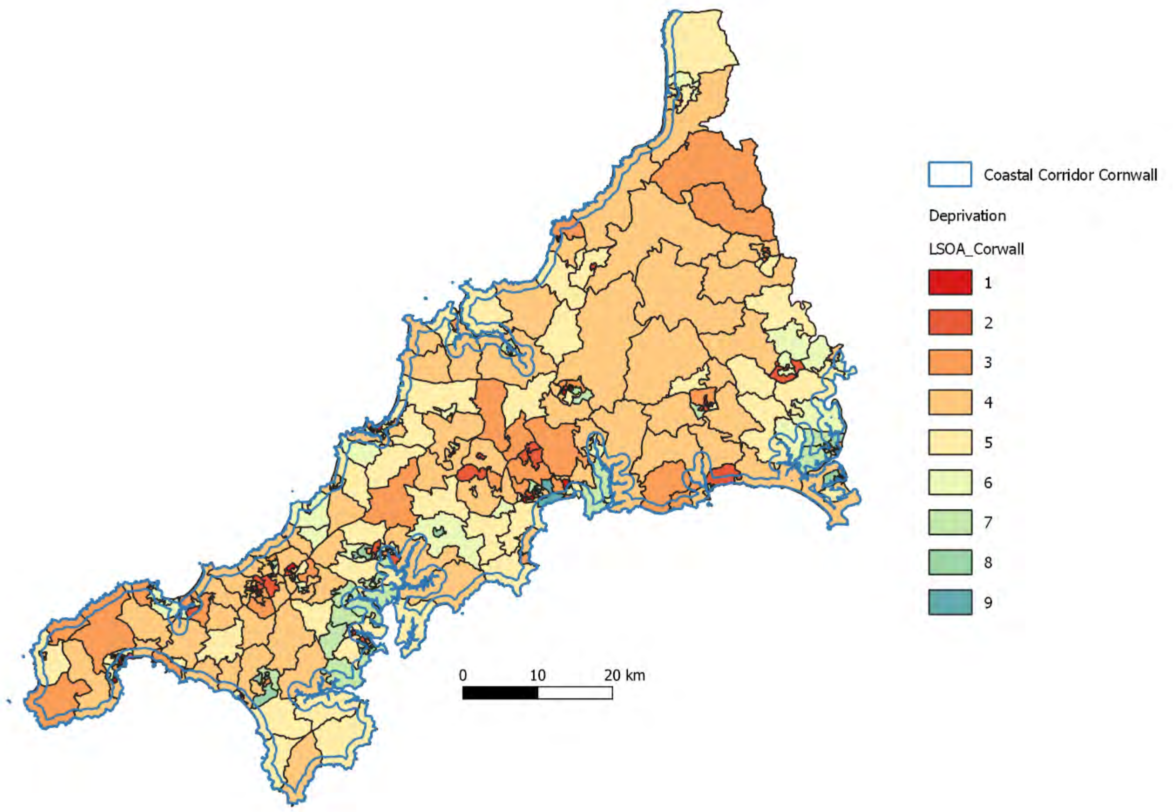
---

[45] https://esriukeducation.maps.arcgis.com/apps/Cascade/index.html?appid=3c16c360b5704192a550f844b13ffb0a
[46] ONS (2015) https://www.gov.uk/government/statistics/english-indices-of-deprivation-2015; https://www.ons.gov.uk/aboutus/transparencyandgovernance/freedomofinformationfoi/indexofmultipledeprivation
[47] https://esriukeducation.maps.arcgis.com/apps/Cascade/index.html?appid=3c16c360b5704192a550f844b13ffb0a
[48] https://www.gov.uk/government/statistics/english-indices-of-deprivation-2015

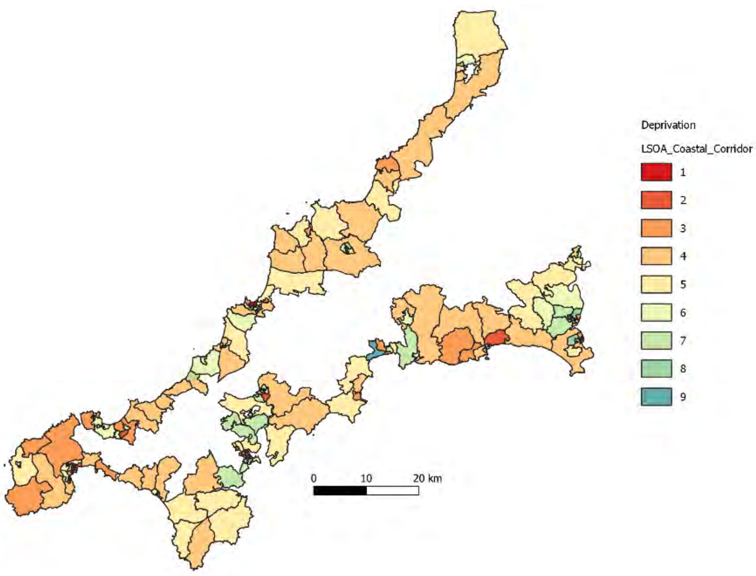
in England (30%). These include neighbourhoods at Hayle, Penzance (Treneee), Newlyn, Falmouth, Penryn, Truro, Newquay, Looe and Torpoint.

LSOA Name (2011)	Index of Multiple Deprivation (Where 1 is most Deprived)	Index of Multiple Deprivation Decile (where 1 is most deprived 10% of LSOAs)
Cornwall 070D	2,938	1
Cornwall 068A	2,147	1
Cornwall 067E	414	1
Cornwall 062D	2,541	1
Cornwall 021C	2,797	1
Cornwall 020B	2,378	1
Cornwall 068C	3,724	2
Cornwall 067D	3,500	2
Cornwall 062E	4,084	2
Cornwall 060C	4,432	2
Cornwall 057E	3,598	2
Cornwall 042D	6,330	2
Cornwall 029A	5,524	2
Cornwall 028E	4,428	2

Table 7. 10% most deprived LSOA (neighbourhoods) intersecting the coastal corridor (ONS 2015)



Map 5. Deprivation LSOA by Decile of deprivation (1 = 10% most deprived 10 = 10% least deprived) (Source ONS 2015)



Map 6. LSOA Deprivation by Decile of Deprivation (1 = 10% most deprived 10 = 10% least deprived) (Source ONS 2015)

	Coastal Corridor	Rest of Cornwall	Cornwall
All Deprivation classification households	107811	124764	232575
Household is not deprived in any dimension	40.9%	39.6%	40.2%
Household is deprived in 1 dimension	34.8%	34.5%	34.6%
Household is deprived in 2 dimensions	19.2%	20.5%	19.9%
Household is deprived in 3 dimensions	4.6%	5.0%	4.8%
Household is deprived in 4 dimensions	0.50%	0.49%	0.5%

Table 8. Deprivation Classification of Households in Output Areas intersecting the coastal corridor compared to the rest of Cornwall, ONS Census 2011

3. ECONOMIC CHARACTERISTICS

3.01 Gross Value Added

- *The Gross Value Added (GVA) for the coastal corridor is estimated to range between £3,757 million and £4,179 million per year, which is around 38%-44% of Cornwall's total GVA. It is important to note that these estimates are subject to the effects of commuting and variations in the age structure of populations.*
- *The largest contributions to the coastal corridor's GVA are derived from public administration, education and health (23%); real estate (19%); distribution and transport, accommodation and food (18%); and construction (12%). These sectors largely reflect the most important sectors for GVA in Cornwall, with the exception of the construction sector which is of higher importance to GVA in the coastal corridor than in Cornwall as a whole.*
- *Assessing the coastal corridor GVA as a percentage of total GVA per sector in Cornwall indicates that: the coastal corridor is particularly important for financial and insurance activities, where the coastal corridor contributes 72% of total GVA from this sector, information and communication (69%), construction (68%) and other services and household activities (51%).*

Gross Value Added, or GVA, is an estimate of the state of economic activity from the producer's or supply-side perspective. Providing a measure of the contribution to the economy of each industry or sector, GVA is calculated by measuring the value of the goods or services as they leave a sector, industry or area, minus the cost of inputs used to produce them. GVA can be used to provide an impression of the sectoral structure of Cornwall's economy and give some indication of the contribution made by the coastal corridor. There are however a number of commonly cited limitations of GVA as a measure of economic productivity, including a failure to capture the value of certain activities, e.g. caring for children or volunteering, and a lack of adjustment for negative externalities. Furthermore, income-based approaches to calculating GVA can be subject to distortion due to the effects of commuting and variations in the age structure of populations (ONS 2017[49]). Despite these limitations, GVA and GVA per head are widely used indicators of the economic well-being of an area and provide a means of comparison/benchmarking with other areas.

Until very recently, it has been unusual for GVA to be published at geographical scales below the region or county. ONS estimates of GVA are only available for existing administrative and statistical areas down to the Local Authority level and are not available for local areas such as Census OAs or wards. Consequently, GVA estimates cannot be calculated for the coastal corridor using best-fit methods as used throughout Section 2. Instead, GVA has to be estimated using assumptions about the economic characteristics and residents of the coastal corridor following the approaches set out in the Valuing England's National Parks Study (Cumulus Consultants Ltd and ICF GHK, 2013[50]).

The Valuing England's National Park study highlights that GVA can be estimated for non-statistical geographies using: (1) GVA per business, (2) per worker, or (3) per £1 of output, based on relevant data at the national and county level (Cumulus Consultants Ltd and ICF GHK, 2013). Calculating GVA per business uses estimates of the GVA generated per £1 of output across different sectors to generate a ratio of GVA per unit of turnover, this would then be applied to an estimated turnover of sectors present in the study area. Although GVA per business can provide good estimates of GVA, local turnover data were not available for the coastal corridor and therefore it has not been possible to use this method. Estimating GVA per worker uses LA total GVA estimates and proportions these per sector and per worker. GVA per worker and sector can then be linked to the level of employment per sector in the study area. This approach calculates a GVA value per job by broad sector, which is then attributed to the number of workers in each sector in a specific area, it is however limited due to the effects of commuting. Furthermore, this approach is likely to provide an over-estimate of local GVA where there is a focus on relatively low-value economic activities such as agriculture and tourism. Simpler estimates can be made using broad estimates of local level employment (GVA per employee) and average GVA per worker for the LA.

The GVA per worker approach was adopted to calculate GVA for the coastal corridor, as estimates of worker numbers in the coastal corridor were available (see Section 2.08) (Table 9). Using this approach (see table 9) the GVA of the coastal corridor was estimated to be £4,179 million, 44% of the total GVA in Cornwall of £9,579 million[51] (ONS 2016). In addition, GVA per employee was calculated based on estimates of total local level employment and average GVA per employee in Cornwall, which resulted in a lower estimate

[49] *ONS (2017) https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/regionalgvaibylocalauthorityintheuk*
[50] *Cumulus Consultants Ltd and ICF GHK (2013) https://www.nationalparksengland.org.uk/__data/assets/pdf_file/0004/717637/Valuing-Englands-National-Parks-Final-Report-10-5-13.pdf*
[51] *GVA by sector 3-year average (2013-2015 £million), Source ONS (2016) https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/regionalgrossvalueaddedbalancedbylocalauthorityintheuk*

of £3,757 (million) or 38% of total GVA in Cornwall (Table 10). Both estimates are limited as they do not take into account the effects of commuting.

Cornwall's GVA (income) and employment give an indication of the importance of certain industrial sectors to the economy and working communities[52]. The most important sectors for GVA in the coastal corridor were found to be public administration, education and health (23%), real estate (19%); distribution, transport, accommodation and food (18%); and construction (12%). As shown in Table 9, the importance of sectors for GVA in the coastal corridor is very similar to the whole of Cornwall, with the exception of the construction sector which is of higher importance to GVA in the coastal corridor. Assessing the coastal corridor GVA as a percentage of total GVA per sector in Cornwall indicates that the coastal corridor is particularly important for: financial and insurance activities, where the coastal corridor contributes 72% of total GVA from this sector, information and communication (69%), construction (68%) and other services and household activities (51%).

Cornwall Council suggest that Cornwall's economy has grown most in areas relating to tourism and ageing population, whilst agriculture is in decline in terms of contribution to GVA (Cornwall Council 2016[53]). Monitoring of the economy by Cornwall Council suggests growth in the following areas in terms of GVA: (1) public administration – but falling employment and productivity, (2) construction – but falling productivity, (3) retail distribution, (4) food and drink manufacturing, (5) air transport, (6) finance and (7) social welfare. There have however been declines in the GVA contribution made by the fishing, mining and quarrying sectors (Cornwall Council 2016).

GVA per worker (employment based GVA estimates) Sector	Workers in Cornwall[54]	GVA by sector (£ million) (2015 ONS)[55]	% total GVA	Cornwall GVA per worker	Workers in the coastal corridor per sector[56]	GVA per sector in coastal corridor	% of total Corridor GVA	CC GVA as % total GVA per sector Cornwall
Agriculture, forestry and fishing	4500	240	3%	£53,259	1713	£91,232,667	2%	38%
Production other than manufacturing	3000	304	3%	£101,222	1106	£111,951,532	3%	37%
Manufacturing	16000	737	8%	£46,042	5917	£272,430,514	7%	37%
Construction	11000	729	8%	£66,303	7422	£492,100,866	12%	68%
Distribution; transport; accommodation and food	76000	2078	22%	£27,346	27698	£757,429,508	18%	36%
Information and communication	2500	178	2%	£71,067	1722	£122,377,374	3%	69%
Financial and insurance activities	2000	164	2%	£82,167	1444	£118,649,148	3%	72%
Real estate activities	3500	2060	22%	£588,476	1380	£812,096,880	19%	39%
Business service activities	24000	627	7%	£26,111	8327	£217,426,297	5%	35%
Public administration; education; health	55000	2045	21%	£37,176	26083	£969,661,608	23%	47%
Other services and household activities	10000	418	4%	£41,833	5109	£213,724,797	5%	51%
Total		£9,579 million				£ 4,179 million		43.6%

*Table 9. Employment based GVA estimates for Cornwall Coastal Corridor by Sector (using 2015 and 2011 ONS data) (*Not adjusted to 2018)*

GVA per employee (GVA estimates based on county level productivity)	Economically Active Cornwall (2015[57])/2011 Census	GVA per employee/worker (£)	Estimated GVA (2015)
Cornwall	244,800	£40,236.9	£9,850 (million)
Coastal Corridor	93,384	£40,236.9	£3,757 (million)

*Table 10. GVA per employee estimates for the coastal corridor and Cornwall (GVA estimates based on county level productivity) (*not adjusted to 2018 prices)*

3.02 Businesses/Enterprises

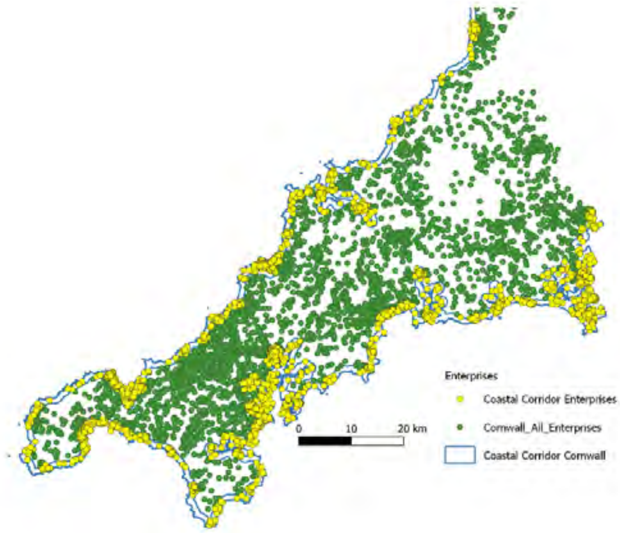
- *44% [9225] of all enterprises in Cornwall registered with Companies House fall within the coastal corridor, this excludes enterprises not registered for VAT or PAYE.*
- *Notably the coastal corridor contains 39% of large enterprises in Cornwall, 24% of medium enterprises, 42% of minor enterprises and 46% of small enterprises.*

---

[52] *Looking at the size of sectors only in relation to GVA does not provide a complete picture of productivity and also the number of people employed.*
[53] *Source: https://www.cornwall.gov.uk/media/17635607/state-of-the-economy-jan16.pdf*
[54] *Workers by Industry Employed in (ONS 2015) (Business register and employment survey ONS 2015)*
[55] *GVA by sector 3-year average (2013-2015 £million)*
[56] *See Section 2.08 (Census 2011)*
[57] *Source: https://www.cornwall.gov.uk/media/17635607/state-of-the-economy-jan16.pdf*

3.02.01 Number of enterprises

There are an estimated 23,795 registered enterprises in Cornwall and the Isles of Scilly (VAT and/or PAYE businesses), with 28,045 business units[58] (ONS 2018[59]). An enterprise is the smallest combination of legal units which has a certain degree of autonomy within an enterprise group. The number of registered enterprises in Cornwall has steadily grown between 2010 and 2018 with an increase of 14% from 2010 levels (ONS 2018). Cornwall contains 10% of all registered enterprises in the SW (ONS 2018). Companies House[60] provides information on only 20,790 registered enterprises in Cornwall (87%) (TEVI pers comm; Companies House 2019[61]), this excludes enterprises not registered for VAT or PAYE. Once mapped across Cornwall, 9225 enterprises fall within or intersect the coastal corridor (44%) (Map 7). As to be expected, enterprises cluster around urban centres, including Penzance, Truro, St Ives and Newquay. Within the coastal corridor, the density of enterprises per ha is 0.14 while it drops to 0.039 per ha for the rest of Cornwall. Notably, Cornwall is distinct in terms of its distribution of businesses as the number located in rural areas is significantly higher than in urban areas (Whittaker 2017[62]). The rural/urban ratio in Cornwall is 2:1; SW 1:1; and England 1:3.



Map 7. Enterprises in Cornwall (green) in the coastal corridor (yellow)

3.02.02 Scale of enterprises

Different estimates are available of the number of employees for enterprises across Cornwall. ONS (2018) data suggest that 88% of all enterprises in Cornwall are micro (Table 11), whereas the Companies House dataset suggests 98% of enterprises are micro scale (see Tables 12 and 13). Only the Companies House dataset is mappable and has been used to establish the number of employees per enterprise within the coastal corridor. Table 13 shows little difference between the number of employees per enterprise between the coastal corridor and the rest of Cornwall. Notably, the coastal corridor contains 39% of large enterprises, 24% of medium enterprises, 42% of minor enterprises and 46% of small enterprise in Cornwall. There is a slightly higher percentage of micro enterprises within the coastal corridor, which fits with findings in Section 2.07 of the higher percentage of self-employed usual residents in the coastal corridor. There is a "*fuzzy line*" between self-employment and micro-businesses, hence the '*real'* number of enterprises could be higher. The largest companies (+250 employees) withinthe coastal corridor are listed in Table 14.

Enterprises	Cornwall (ONS 2018)	
	(Numbers)	(%)
Micro (0 to 9)	20,980	88.2
Small (10 to 49)	2,455	10.3
Medium (50 to 249)	295	1.2
Large (250+)	65	0.3
Total	23,795	

Table 11. UK Business Counts enterprises by number of employees in Cornwall (Source: ONS 2018)

[58] *This figure is an estimate as businesses do not fall neatly into pre-defined sectors and they defy easy measurement through official statistics.*
[59] *ONS (2018)UK Business Counts - Inter Departmental Business Register: https://www.nomisweb.co.uk/reports/lmp/la/1946157349/report.aspx?#tabidbr*
[60] *Companies House https://www.gov.uk/government/organisations/companies-house*
[61] *https://beta.companieshouse.gov.uk/*
[62] *Whittaker (2017) Cornwall's Vital Issues 2017 Report: https://www.cornwallcommunityfoundation.com/wp-content/uploads/2018/12/Cornwalls-Vital-Issues-2017-Final-2.pdf*

Enterprises	Cornwall (Companies House)	
	Count	(%)
Micro (0 to 9)	14626	97.8%
Small (10 to 49)	116	0.8%
Medium (50 to 249)	142	0.9%
Large (250+)	67	0.4%
Total	14951	

Table 12. Enterprises by employee number in Cornwall (Companies House 2019; TEVI)

Enterprises (number of employees)	Coastal Corridor		Rest of Cornwall		% of total in Cornwall
	Count	%	Count	%	
Micro (0 to 9)	6665	98.0%	7961	97.7%	46%
Small (10 to 49)	49	0.7%	67	0.8%	42%
Medium (50 to 249)	59	0.9%	83	1.0%	42%
Large (250+)	26	0.4%	41	0.5%	39%

Table 13. Companies House enterprises by number of employees in the Coastal Corridor and the rest of Cornwall (Companies House 2019; TEVI)

Company Name	Employees	Sector	Address
IMERYS MINERALS LIMITED	1038	Mineral processing, mines and quarries	Par Moor Centre, Par Moor Road, Par, PL24 2SQ
CORSERV LIMITED	1994	Council owned - diverse	Higher Trenant Rd, Wadebridge PL27 6TW
CORMAC SOLUTIONS LIMITED	1743	Council owned – Construction, facilities and plant maintenance	Higher Trenant Rd, Wadebridge PL27 6TW
GILLETT'S (CALLINGTON) LIMITED	494	Food services activities	Gilletts Callington Limited Forge Lane Moorlands Trading Estate Saltash PL12 6LX
VIA EAST MIDLANDS LIMITED	578	Design, construction and highways, Joint venture company, Council and CORSERV	Hall New County Hall Treyew Road Truro Cornwall TR1 3AY
PENDENNIS SHIPYARD (HOLDINGS) LIMITED	402	Marine	The Docks, Falmouth TR11 4NR
PENDENNIS SHIPYARD LIMITED	394	Marine	The Docks, Falmouth TR11 4NR
H.TEMPEST LIMITED	788	Photographic and film processing	The Colour Laboratory, Lelant, Saint Ives TR26 3HU
SOUTH EAST CORNWALL MULTI ACADEMY REGIONAL TRUST	469	Education	Wearde Road, Saltash Cornwall, PL12 4AY
NEWQUAY EDUCATION TRUST	354	Education	Newquay Tretherras, Trevenson Road, Newquay Cornwall, TR7 3BH
SPECIAL PARTNERSHIP TRUST	307	Education	Pencalenick School, St Clement, Truro, TR1 1TE
PROVENANCE BRANDS LIMITED	564	Food services activities	Ocean House Lower Quay, Gweek, Helston, Cornwall, TR12 6UD
CORNWALL GLASS & GLAZING LIMITED	296	Construction	Old Mansion House, 9 Quay Street, Truro, Cornwall, England, TR1 2HE
SEAFOOD TRADING LIMITED	310	Food services activities	Riverside, Padstow, Cornwall, PL28 8BY
THE SEAFOOD RESTAURANT (PADSTOW) LIMITED	310	Food services activities	Riverside, Padstow, Cornwall, PL28 8BY
THE LEARNING ACADEMY TRUST	316	Education	Treloggan Ln, Newquay TR7 1HX
RED HOTELS LIMITED	344	Accommodation and Hospitality	The Scarlet Hotel, Tredragon Rd, Mawgan Porth, Newquay TR8 4DQ
ATLANTIC CENTRE OF EXCELLENCE MULTI ACADEMY TRUST	375	Education	St Columb Minor ACE Academy, Porthbean Road, Newquay TR7 3JF
THE CORNISH BAKERY SHOPS LIMITED	291	Food services activities	7 Arwenack Street, Falmouth, Cornwall, TR11 3HZ
WATERGATE BAY HOTEL LIMITED	283	Accommodation and Hospitality	Watergate Bay Hotel, Watergate Bay, Newquay, Cornwall, TR8 4AA
NETTLETON HOLDINGS LIMITED	277	Real Estate and Property Management	Lowin House, Tregolls Road, Truro, Cornwall, TR1 2NA
SWALLOWCOURT HOLDINGS LIMITED	414	Care and human health	Peat House Newham Road Truro, Cornwall TR1 2DP
CORNWALL HOSPICE CARE LIMITED	283	Care and human health	Mount Edgcumbe Hospice, Porthpean Rd, Saint Austell PL26 6AB
PORTHIA GROUP LIMITED	338	Real Estate and Property Management	Godrevy House, Trewidden Road, St Ives, Cornwall, TR26 2BX
SWALLOWCOURT LIMITED	317	Care and human health	Peat House Newham Road Truro, Cornwall TR1 2DP
BEDRUTHAN HOTEL LIMITED	344	Accommodation and Hospitality	Bedruthan Hotel and Spa Cornwall Trenance, Mawgan Porth TR8 4BU

Table 14. Enterprises with more than 250 employees within the coastal corridor (Source: Companies House 2019)

3.02.03 Enterprises by sector/industry

Enterprise counts by industry give an indication of the importance of an area for different industries and the largest industries in an area. Agriculture, forestry and fishing are the largest industry group by enterprise count in Cornwall, accounting for 18% of all registered enterprises, construction accounts for 14% of all registered enterprises, while accommodation and food services and professional, scientific and technical enterprises both account for 10%. Notably, both the agriculture, forestry and fishing industry and accommodation and food services industry are closely dependent on natural capital assets. A full dataset from which to map enterprises by sector was not available for the coastal corridor and instead only qualitative information and grey literature were available from which to indicate the spatial distribution of different sectors and industries in relation to the coast.(see Table 15)

Industry	Cornwall[63]	
	Count	%
A : Agriculture, forestry and fishing	4240	18%
B : Mining and quarrying	25	0.1%
C : Manufacturing	1250	5%
D : Electricity, gas, steam and air conditioning supply	135	1%
E : Water supply; sewerage, waste management and remediation activities	60	0%
F : Construction	3260	14%
G : Wholesale and retail trade; repair of motor vehicles and motorcycles	3435	14%
H : Transportation and storage	600	3%
I : Accommodation and food service activities	2335	10%
J : Information and communication	815	3%
K : Financial and insurance activities	255	1%
L : Real estate activities	760	3%
M : Professional, scientific and technical activities	2410	10%
N : Administrative and support service activities	1510	6%
O : Public administration and defence; compulsory social security	160	1%
P : Education	315	1%
Q : Human health and social work activities	860	4%
R : Arts, entertainment and recreation	570	2%
S : Other service activities	810	3%

Table 15. Distribution of enterprises by Business Sector in Cornwall (Source: Nomis, UK Enterprise Counts 2015)

There is some notable spatial clustering of industries in relation to the coastal corridor. There are clusters of marine-based businesses (including marine civil engineering) in and around Falmouth (42%) which directly and indirectly employ some 14,000 workers in Cornwall (CIoSLEP 2012[64]). The Falmouth area is of particular importance for boat building and ship repair (e.g. A&P Falmouth and Superyachts builders). Tourism and recreational enterprises also have a clear presence throughout the coastal corridor and can be seen as the economic bedrock of the area. Many tourism and leisure enterprises have increased their profile over recent years, and retain a significant relationship to the natural environment (CIoSLEP 2012).

In contrast, major food producing enterprises are not particularly spatially clustered and are instead disturbed widely across Cornwall but have significant local supply chains with links to the coastal corridor or branding linked to the coastal identity of Cornwall (LEP 2012). A lack of spatial clustering is also true for digital/new media and creative activities (e.g. Spider-eye Animation) which are again found across the geography of Cornwall (LEP 2012).

In terms of turnover, the areas with the highest proportion of businesses with over £1 million turnovers are inland, Camborne and Redruth, but these are closely followed by St Austell and Newquay which lie within the coastal corridor. However, in absolute numbers, North Cornwall has the greatest number of business with over £1 million turnovers (315) (CIoSLEP 2012). North Cornwall area is also in the lead when it comes to agricultural business (27% - 5,005 businesses), followed closely by South East Cornwall with 22% of businesses operating in the agricultural industry. In contrast, Truro and Falmouth and St Austell and Newquay have less than half the proportion of agricultural businesses as North Cornwall but have the greatest proportion of professional, scientific and technical businesses (14%) and construction businesses (12%). North Cornwall, St Ives and St Austell & Newquay have the highest proportion of accommodation & food businesses.

A number of predicted growth areas for sectors in Cornwall are highlighted by Cornwall LEP and Cornwall Council (Buckham and Southern 2017[65]). Cornwall Council has utilised models from both Experian and Cambridge Econometrics which have produced

[63] Nomis, UK Enterprise Counts (2015)
[64] http://www.sqw.co.uk/files/2313/8531/4708/Strat_5.pdf
[65] Buckham and Southern (2017) https://www.cioslep.com/assets/file/Cornwall%20and%20IoS%20Employment%20and%20Skills%20Strategy%20Appendix%201_P1.pdf

similar estimates of growth and identified the shared projections. Broadly, Buckham and Southern (2017) identify the following trends: (1) growth in professional, scientific and technical businesses following the national trend, (2) growth of higher skilled jobs (16% in Cornwall) (Buckham and Southern, 2017), (3) growth in maritime industries and the renewable energy/environment technology sector, (4) growth in the care sector (health or social care) and leisure roles, reflecting the influence of demographic changes such as ageing on service requirements, (5) a diminishing role of public sector employment in terms of overall employment growth, (6) decline in manufacturing employment, and (7) growth in the accommodation and food services sector (See Table 16).

10 largest sectors in 2030 (by employment)		10 Fastest Growing Sectors (By employment 2014-2030)	
Food and beverage services	11%	Other manufacturing and repair	91.8%
Retail trade	10%	Chemicals	67.2%
Construction	9%	Food and beverage services	49.3%
Education	7%	Other professional services	34.1%
Health	7%	Business support services	29.7%
Residential and social	7%	Arts	27.1%
Business support services	6%	Other services	25.3%
Accommodation	5%	Residential and social	19.3%
Other services	4%	Construction	13.9%
Public Administration and Defence	4%	Other transport equipment	13.2%

Table 16. Ten largest sectors and ten fastest growing sectors (Cambridge Economic April 2015 forecast)

3.03 Sectoral Analysis

This section explores the significance of the coastal corridor for target sectors. The sectors included have been selected based on their relevance to the coastal corridor (enterprise counts/scale) and their clear link to the natural capital assets present in the coastal corridor (see Section 4). This analysis is limited to only a few niche target sectors, considered to be particularly relevant to the One Coast project focus on the coastal corridor stretching from mean high water to 1km inland, and limited to established sectors. The aim of this section is to provide a quick snapshot of the target sectors and, where possible, estimate the potential significance of the coastal corridor.

3.03.01 Tourism

- *Tourism is a main driver of the Cornish economy, it is also a sector which is "inextricably linked to Cornwall's unique environment, including its coastline and cultural heritage" (Cornwall Council 2012[66]).*
- *53% of tourist sites (broadly defined) lie within or intersect the coastal corridor (e.g. campsites, hotels, beaches, coves, nature reserves, museums, monuments, holiday cottages etc.).*
- *There are an estimated 5.34 million day/staying visits per year (SWRC 2016[67], 2018[68]) to coastal areas in Cornwall, 28% of total tourism visits. For 12% of visitors (2.28 million) walking in the coastal corridor is the sole reason for their visit.*
- *Looking specifically at the coastal corridor, the SW Research Company (SWRC 2016[69]) suggests that the corridor receives an estimated 2.26 million visitors per year (2010-2015 average visitor numbers) based on estimates for the Cornish section of the coastal path estimates. However, the number of visitors to the coastal corridor could be as high as 14.88 million visitors per year (SWRC 2016), or 78% of total visitors.*
- *Visitor spend in all coastal areas is estimated to be around £666 million per year (including day trip and staying visitors), 34% of average visitor spend 2010-2015 (SWRC 2016, 2018).*
- *Visitor spend in the coastal corridor can be extrapolated from visitor numbers. Looking solely at 'other coastal areas, excluding beaches', average annual spend is estimated to be £178 million per year (2010-2015 average) equating to on average 10% of the total visitor spend in Cornwall and 26% of coastal spend (SWRC 2016, 2018[70]).*

[66] Cornwall Council (2012) Economy and Culture Strategy Evidence Base - https://www.cornwall.gov.uk/media/3624007/Economy-and-Culture-Strategy-Evidence-Base.pdf
[67] Please note that this data excludes regular non-tourism related residential use such as dog walking.
[68] SWRC (2018) Cornwall Visitor Survey 2018/19 Quarterly update, Produced on behalf of Visit Cornwall.
[69] SWRC (2016) SW Coast Path Monitoring and Evaluation Framework, Year 5 (2015) Key Findings, Produced on behalf of the SW Coast Path Team.
[70] Observatory of the Cornwall Marine Leisure Industry Draft in preparation 2010. Nautisme Espace Atlantique Project, Cornwall Development Company.

Tourism in Cornwall

The tourism industry is considered a cornerstone or bedrock industry of the Cornish economy (Cornwall Council 2012[71], 2011[72]). Annual visitor spend estimates suggest that the tourism industry has a value of around £1.95 billion per year to the Cornish economy (SWRC 2018). There are an estimated 19.06 million visitors (domestic and international) to Cornwall every year (3 year rolling average 2015-2017), this includes 4.7 million staying visitors and 14.4 million day visitors (Visit Cornwall 2017[73]). As a percentage of total Gross Value Added (GVA) estimates suggest that the tourism industry contributes between 9.9% to 16% (SWRC 2014[74]; S4W 2017[75]). The significance of the tourism industry to the Cornish economy is highlighted by the ONS (2013[76]) tourism ratio. The tourism ratio measures the economic importance of tourism within a sub-region, calculated by dividing the total demand within an area (visitor expenditure) by total supply (or overall output of all industry) in the region (ONS 2013). Cornwall and the Isles of Scilly have a tourism ratio of 9.9%, considerably higher than the UK average, 3.7%, and the average for the SW (4.5%). Cornwall and the Isles of Scilly have the top tourism ratio out of all sub-regions in the UK (ONS 2018). Furthermore, 12.9% of all enterprises in Cornwall are thought to be directly or indirectly linked to tourism and recreation (SWRC 2018). The tourism industry is also estimated to be directly or indirectly linked to some 17-25% of all employment in Cornwall, with 54,000 people employed directly or indirectly through the tourism industry in 2018 (SWRC 2018[77][78]; S4W 2017). In comparison, tourism is only linked to 12% of employment in Devon and Dorset and 9% in Somerset. Cornwall's tourism season is also thought to be extending, with a growing number of visitors outside of the summer period, which could see the value of the sector continue to grow. High visitor numbers come with inevitable challenges for the local infrastructure and services, as well as placing pressure on the natural environment. Notably, Cornwall Council has already acknowledged that any growth of the tourism industry is reliant on natural capital, highlight that "improvements to the status of Cornwall's natural and historic marine environment will enhance tourism and leisure activities whilst also improving awareness and understanding" *(Cornwall Council 2012[79]).* The Council's position provides a strong basis for investment in the natural capital assets of the coastal corridor as a means to invest in the future growth and resilience of the tourism sector[80]). However, thus far major tourism investment projects in the coastal corridor have focused on cultural heritage (SWCP 2016[81]).

Total value of Tourism to Cornwall's Economy	£1,951,266,000
Staying plus day visitor spend plus other tourism spend	
Total Employment (Actual)	54,452
Direct Employment (Actual)	36,570
Indirect/Induced Employment (Actual)	17,882
**3 year rolling average (2015-2017)*	
Total Employment FTE	40,629
Direct Employment (FTE 's)	24,943
Indirect/Induced Employment (FTE 's)	15,686
% Of All Employment	21%
As a % of all employment in area.	
Estimated contribution to Cornwall's GVA	£1,555,867,333
Total tourism supported business turnover	£2,792,910,333

Table 17. The Value of tourism for Cornwall (Source: SWRC 2018)

[71] Cornwall Council (2012) A future for maritime Cornwall: The Cornwall Maritime Strategy 2012-2030, Annex: background information 2, https://www.cornwall.gov.uk/media/3623049/Annex-background-information-2-.pdf

[72] Cornwall Council (2011) Tourism Issues Paper, Core Strategy Evidence Papers, Cornwall Council Planning Department, https://www.cornwall.gov.uk/media/3639137/Tourism.pdf

[73] Visit Cornwall (2017) Value of Tourism in Cornwall 2017, The SW Research Company.

[74] Visit Cornwall and Cornwall Council (2014) Cornwall's Visitor Economy Strategy 2014-2020, Consultation Document, https://www.visitcornwall.com/sites/default/files/generic_files/Cornwall%20Visitor%20Economy%202014-20%20Consultation.pdf

[75] S4W (2017) Economic and Social Impacts of EEA Area Workers in Cornwall and the Isles of Scilly, Research Report, Cornwall Council and the Cornwall and Isles of Scilly Local Enterprise Partnership Cornwall Council, https://www.cioslep.com/assets/file/Economic%20and%20Social%20Impacts%20of%20EEA%20Area%20Workers%20on%20Cornwall%20and%20the%20Isle.pdf

[76] ONS (2013) ONS Regional Tourism Ratios https://www.ons.gov.uk/peoplepopulationandcommunity/leisureandtourism/articles/theregionalvalueoftourismintheuk/2013

[77] Tourism Ratio at the Sub-regional level in the UK 2013 (top 15) Source: UK TSA (2013) ONS IO & SUIT 2013: Annual Business Survey 2013, GB Day Visits Survey 2013; GB Tourism survey 2013; International passenger survey 2013

[78] SW Research Company Ltd and Visit Cornwall (2018) The economic impact of Cornwall's Visitor Economy 2017; Cornwall Annual Population Survey (2016) employment in Tourism; Cornwall Futures Group (2017) A Catalyst for Change – Implications, Risk and Opportunities of Brexit for Cornwall and the Isles of Scilly, CIoS Futures Group, January 2017 https://www.cornwall.gov.uk/media/24227365/catalyst-for-change-brexit-report.pdf

[79] Cornwall Council (2012) A future for maritime Cornwall: The Cornwall Maritime Strategy 2012-2030, Annex: background information, https://www.cornwall.gov.uk/media/3623049/Annex-background-information-2-.pdf

[80] Science and Policy Integration for Coastal System Assessment. http://www.spicosa.eu/index.htm

[81] https://www.southwestcoastpath.org.uk/media/uploads/swcp_year_5_analysis_summary_-_key_findings.pdf

3 year rolling average 2015-2017	Trips	Estimated Spend
Combined Day Trips and Staying Visits	19,061,000	£1,889,020,333
Day-visits	14,391,333	£505,130,333
Staying visits (UK and Overseas visitors)	4,669,667	£1,383,890,000

Table 18. Tourism visitor numbers and spend in Cornwall (Source: SWRC 2018)

Tourism and the coastal corridor

Tourism is a main driver of the Cornish economy[82], it is also a sector which is "*inextricably linked to Cornwall's unique environment, including its coastline and cultural heritage*" (Cornwall Council 2012). Cornwall's coastal setting is often referred to as the main draw for tourists, alongside its maritime and cultural heritage. Therefore, the strength of the tourism industry can be considered heavily reliant on the quality of its natural maritime environment, characterised by its long and varied coastline of coves and dramatic cliffs, accessible sandy beaches and dunes, inshore waters and traditional fishing villages and harbours (Cornwall Council 2012).

Given the '*inextricable*' connection between tourism and Cornwall's coastal geography, it is difficult to try to extract the value of the coastal corridor from the wider value of the tourism sector. Indeed, the significance of the coastal corridor for the Cornish tourism sector has never been formally reviewed. However, there are a number of existing studies which provide some estimates of the value of the features of the tourism industry which lie within the coastal corridor, including studies of the economic value of the SW coastal path and the marine leisure industry. The figures reported in the following paragraphs should, however, be acknowledged as likely to be an underestimate of the wider value of the coastal corridor for the Cornish tourism sector.

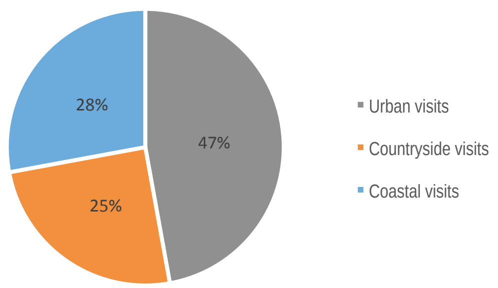
Tourist sites

Out of a total of 1,185 spatial features linked directly to the tourism sector (including YHA, hotels, campsites, tourist attractions, beaches, nature reserves, historic sites and monuments, country houses, covers, holiday cottages, museums etc.), 52.9% [628] lie within or intersect the coastal corridor.

Visitor Numbers

A number of approaches can be used to try to estimate the number of visitors to the coastal corridor.

Firstly, estimates of visits to Cornwall's coastal areas can be made using data collected under the GB Day Visit Survey (GBDV[83]). The GBDV records the number of days visits to different locations including urban, countryside and coastal visits. In Cornwall, an estimated 28% of day trips were thought to be to coastal areas (SWRC 2016[84]). Based on the assumption that any visit to a coastal area can also be counted as a visit to the coastal corridor, these figures suggest that there are at least 5.337 million coastal visits per year[85] in Cornwall (SWRC 2018[86]; Table 19).



Graph 4. Proportion of Tourism Visits to urban, countryside and coastal areas (SWRC 2016)

In 2016 the SW Research Company estimated visitor numbers specifically for the SW Coastal Path, which runs through the coastal corridor. Visitor estimates were based on a face-to-face survey alongside analysis of three national tourism surveys: Great Britain Tourism Survey, Great Britain Day Visits Survey and the International Passenger Survey. The SWRC (2016) worked to refine visitor estimates to try and capture visits solely to the coastal areas but not including beaches (i.e. above MHW). The SWRC defined a visit to the coastal path as *"any visit to an 'other coastline area' as opposed to a beach, resort or town for leisure purposes and in line with the day visitor definition*" (SWRC 2016). As this definition is focused on coastal areas excluding beaches but not adjacent coastal areas it also broadly fits with the definition of the coastal corridor when the values for Cornwall alone are extracted. The estimates made by the SWRC (3026) suggests that the coastal corridor received around 2,260,995 visitors per year (based on average visitor numbers 2010-2015) (Table 19).

[82] Cornwall Council (2012) Economy and Culture Strategy Evidence Base - https://www.cornwall.gov.uk/media/3624007/Economy-and-Culture-Strategy-Evidence-Base.pdf
[83] GBDV https://www.visitbritain.org/gb-tourism-survey-2018-overview
[84] There is no accompanying figure for staying visitors and therefore the figures for staying visitors are assumed to be the same as day trips.
[85] Please note that this data excludes regular non-tourism related residential use such as dog walking).
[86] 28% of total visits using a three year rolling average 19 million visits.

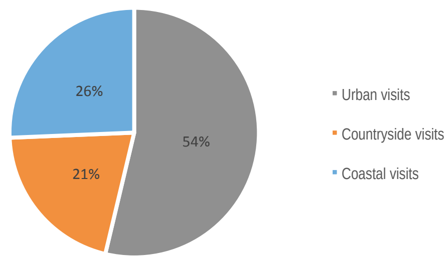
	2010	2011	2012	2013	2014	2015
Total coastal staying visitors	703,010	680,839	658,815	672,004	647,800	740,625
Total day visitors on holiday	402,303	579,340	551,452	576,433	575,209	547,184
Total day visits from home	990,273	985,006	1,044,680	1,070,940	1,083,680	1,056,380
Total SWCP users	2,095,586	2,245,186	2,254,947	2,319,377	2,306,689	2,344,189

Table 19. SWCP visitor numbers (SWRC 2016)

The SWRC (2016) provides one estimate of the visitor numbers to the coastal corridor, however, it is acknowledged as likely to be an underestimate (see the start of section). In comparison additional surveys completed by the SWRC (2016) have suggested that (i) 52% of visitors are likely to walk cliffs and headlands during a visit (9.911 million), and (ii) up to 78% of visitors planned to or had already visited coastal areas (14.48 million) (SWRC 2016). While another observation is that for 12% of visitors (2.28 million) walking in the coastal corridor is the sole reason for their visit.

Visitor Spend

Visitor spend for the coastal corridor can be extrapolated from estimated visitor numbers, as set out in the previous section, combined with data from the GB Day Visit Survey and the Value of Tourism Survey. Spend in coastal areas is estimated to be around £666 million per year (including day trip and staying visitors) (SWRC 2016). Looking solely at other coastal areas, excluding beaches, average annual visitor spend is estimated to be £178 million per year (2010-2015) equating to on average 10% of the total visitor spend in Cornwall and 26% of total coastal spend (SWRC 2016).



Graph 5. Average annual visitor spend by location (Source: SWRC 2018, Average 2017-2011)

Day and Staying Visitor Spending in Coastal Areas (2015-2017 average)	
Coastal day visit spend	£ 128,624,143
Coastal/ non-coastal staying visitor non-accommodation spend in to coastal areas	£ 402,685,862
Coastal staying visits accommodation spend	£ 135,678,400
Estimated Total Spend in coastal areas (staying and day visitors)	£ 666,988,405

Table 20. Day and staying visitor spend in coastal areas (SWRC 2016)

	2010	*2011*	*2012*	*2013*	*2014*	*2015*
Total Spend by SWCP users	£157,959,312	£182,321,476	172,683,102	£184,900,715	£178,902,887	£194,373,901
Total Visitor Spend by county area	£1,580,660,971	£1,821,290,418	£1,765,711,000	£1,804,229,000	£1,754,663,000	£1,865,190,000
	10.0%	10.0%	9.8%	10.2%	10.2%	10.4%

Table 21. Visitor spend for the coastal path (SWRC 2016)

3.04.02 Agricultural Production and Food Processing

Although the value of agriculture production as a proportion of Cornwall's economic output has declined since the 1990s, Cornwall's economy is still more reliant on agricultural production and food processing (hereafter agri-food) than much of the rest of the UK. Nationally, 3% of the UK's Gross Value Added (GVA) is generated through the agri-food sector, while in Cornwall this rises to 6% of GVA (Cornwall Council and CIOS Futures Group 2017[87]). Agricultural production alone is thought to be worth around £217-224 million to the Cornish economy, 2.3% of total GVA (Cornwall Council and CIOS Futures Group 2017). Food-processing accounts for another £248 million, or 2.6% GVA. Collectively the agri-food sector is estimated to employ, directly and indirectly, around 30% of Cornwall's workforce, twice the UK average [15%] (Cornwall Council and CIOS Futures Group 2017). Agriculture is also the largest industry in the County in terms of business numbers (enterprise counts), with an estimated 4535 commercial farm holdings across

[87] *Cornwall Council and CIOS Futures Group (2017) https://www.cornwall.gov.uk/media/30280220/cornwall-council-and-cios-fg_brexit-and-local-government-inquiry-3-2.pdf*

Cornwall (Defra June Survey 2018). The agri-food sector is not only important to the rural economy but more widely to the Cornish economy, through services employment and the purchase of other goods and services in the supply chain economies (Cornwall Futures Group 2017). Enterprises involved in agri-food are widely distributed across Cornwall, however, there is some notable concentration, with two-thirds of all employment in agri-food located in Bodmin, Callington, Illogan, Launceston, Lostwithiel, and St Austell.

Agricultural production

- *The percentage area of agricultural land in the coastal corridor [64%] is notably lower than the percentage area for the rest of Cornwall [76%], this difference reflects the higher areas of urban/suburban and coastal habitats within the corridor and lower area of improved grassland [-26%].*
- *One-third [34%] of Cornwall's best and most versatile agricultural land (grade 1 or 2) lies within the coastal corridor, with the majority found along the southern section of the peninsula.*
- *The coastal corridor is of particular importance for arable and horticultural farm types. Arable and horticultural farm types generate approximately 35% of Cornwall's total agricultural production output (Defra 2018[88]). An estimated 25% of Cornwall's total area of arable and horticultural lands fall within the coastal corridor.*
- *Approximately 372 farms have land intersecting, within or close to the coastal corridor, 8.2% of the total estimated farms in Cornwall. This is an overestimate of the actual number within the corridor (Cumulus Consulting 2017[89]).*
- *Farms with land intersecting the coastal corridor are estimated to benefit from a total CAP basic payment (BPS) contribution of £9,723,000 per year (Cumulus Consulting 2017). The vast majority [99%] of land claimed is non-SDA (Severely Disadvantaged Area), i.e. 'lowland'. BPS equates to an average payment of £241/ha in the coastal corridor, higher than the average for the whole of the SW coastal strip £199.52/ha (Cumulus Consulting 2017).*
- *There are an estimated 253 AES agreement holders with land intersecting the coastal corridor (Countryside Stewardship [CS] and Environmental Stewardship [ES], combined), including approximately 60 CS agreement holders and 193 ES agreement holders. AES agreements cover a total area of some 13,916 ha of the coastal corridor, with a total annual value to agreement holders of £1.597 million, with an average payment of £115/per ha. Cumulus Consulting (2017) found that, in comparison to other areas in the SW coastal corridor, Cornwall benefits from the highest total annual cost (payment), although Dorset has the highest unit annual cost (payment per ha).*

DEFRA's annual farm census[90] provides a detailed picture of holding size, farm types, crop types and areas, livestock number and areas, and farm management for Cornwall. As shown in Table 22, an estimated 274,959 ha of land in Cornwall is thought to be farmed, roughly 74% of Cornwall's total land area (Defra 2018). The majority of farmland in Cornwall is classed as grazing farmland [68%] with a much smaller percentage area devoted to cereal farming [13%], arable and horticultural uses [7%]. The economic output of the agricultural industry in Cornwall is dominated by grazing livestock [65%] including, dairy [30%] and livestock production [29%]. The main dairy purchasers include Milk Link and Dairy Crest. Livestock production largely consists of beef farming [23%], with more limited contribution from pig, sheep and poultry sectors. Notably, Cornwall is considered the second most important area in the UK in terms of quality grazing land, and in the top ten areas in Europe for grazing pasture (Cornwall Council 2012[91]). However, the number of livestock is on a long-term downward trend, and cattle are increasingly concentrated in a few larger herds. Horticulture, including plant and flower production, makes up 17.1% of economic output of the agricultural sector.

Cornwall	Area (ha)	
Total Farmed area	274,959	
%		
Cereals	35851	13%
Arable crops (excl cereals)	16641	6%
Fruit and vegetables	2642	1%
Grassland	187915	68%

Table 22. Cornwall farmed area by farm type (Source: Defra (2016) June agri-census survey)

[88] *Defra June Survey (2018)*
[89] *Cumulus Consulting (2017) The potential impacts of Brexit on the SW Coast land the implications for future agricultural policy, Internal report for the National Trust, unpublished.*
[90] https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june
[91] *Cornwall Council (2012) Agriculture and food issues paper:* https://www.cornwall.gov.uk/media/3638076/Agriculture-and-Food.pdf

	Cornwall	England
Total	% of total number (4571)	
< 20 ha	39%	38%
20 to 100 ha	44%	38%
> 100 hectares or more	17%	24%
		% of total Farmed area
< 20 ha	6%	4%
20 to 100 ha	38%	22%
> 100 hectares or more	56%	74%
		% land use
Grazing livestock	50%	42%
General cropping	17%	17%
Dairy	9%	6%
Livestock Numbers		
Cattle		323,146
Dairy		38%
Beef		32%
Sheep		506,588
Pigs		53,243
Poultry		1,131,335
Total % Output		
Total agricultural output	£477 million	
Livestock	£311 million	(65%)
Crop	£166 million	(35%)
Milk	£143 million	(30%)
Cattle	£109 million	(22.8%)
Plants and flowers	£54 million	(11.3%)
Sheep and goats	£30 million	(6.2%)
Fresh vegetables	£27 million	(5.8%)

Table 23. Cornwall farmland statistics (Source: Defra June Survey 2016 [Eurostat, Economic accounts for agriculture by NUTS 2 regions])

Variations in geography, soils, land ownership and climate, result in differences in the characteristics of the agricultural sector across Cornwall. In general, the North coast of Cornwall is less productive with agriculturally poorer areas, heavy soils (e.g. around Bude), small scale farming predominates in the North coastal plain that is linked to less productive and more exposed land, with a greater likelihood of independent farmers rather than estate land (Cornwall Council[92]). There is a greater amount of pastoral farming around West Penwith, along with important horticultural areas. The South coast is generally more productive, with a greater amount of good mixed farming/grain land and extensive areas of rough grazing around the Lizard. The land between Helston and St Austell sees the dominance of larger farmers, wealthier estates, productive and sheltered lands. Similar characteristics to the Helston and St Austell stretch exist on the coastal corridor between St Austell and Plymouth with productive and shelter areas, but with a higher number of larger farms, and arable based farms, and many farms linked to 4-5 main estates.

Agricultural production in the coastal corridor

Coastal agriculture and food production are important to the local economy, particularly due to the growing emphasis on local and niche products, including Cornish branded products, e.g. Dairy Crest's Davidstow brand. An estimated 64% [41,377 ha] of the coastal corridor is under commercial agricultural use[93] (Table 24). The percentage cover of agricultural land in the coastal corridor is 12% lower than the percentage area in the rest of Cornwall [76%] (Table 24), and this difference reflects the higher areas of urban/suburban and coastal habitats within the corridor. However, compared to the rest of Cornwall, the coastal corridor contains a notably high percentage cover of arable and horticulture areas (+14%) and a much lower percentage cover of improved grassland (-26%). For the farming sector, the coastal corridor is likely to be of particular importance in terms of its contribution to the arable and horticultural farm types, which generate 35% of the Cornish farming total industry's output.

---

[92] Cornwall Council, Cornwall Farmstead Character Statement; https://www.cornwall.gov.uk/media/28925561/cornwall-farmsteads-character-statement2_red.pdf
[93] Classed as arable and horticulture or improved grassland under the LCM (2015).

Land Cover Map Land Type	Coastal Corridor		Rest of Cornwall		Cornwall		CC as % of Cornwall
	Area (ha)	% total area	Area (ha)	% total area	Area (ha)	% total area	
Enclosed Grassland	41376.8	64%	226649.2	75.7%	268026.0	73.6%	15%
Arable and Horticulture	25055.6	38.6%	73564.3	24.6%	98619.9	27.1%	25.4%
Improved Grassland	16321.2	25.2%	153084.9	51.1%	169406.1	46.5%	9.6%

Table 24. Agricultural areas or farmed areas types in the coastal corridor (Source: CEH 2015, Land Cover Map)

Spatially, the importance of certain areas for agricultural production can be indicated through assessing the quality of agricultural land an area contains. Agricultural land quality is classed from Grade 1 (best and most versatile) to Grade 5 (land with very severe limitations which restrict use). Much like the rest of Cornwall, average or lower grade agricultural land is the norm in the coastal corridor, with Grade 3-5 land covering the vast majority [74.5%] of the coastal corridor. However, the coastal corridor contains an estimated 34% [9,885ha] of Cornwall's best and most versatile agricultural land (Grade 1 or 2). The concentration of high-quality agricultural land in the coastal corridor is linked to the productive sheltered lands along the south coast, which contain large areas of grade 2 land. Based on average UK agricultural land prices the coastal corridor has an estimated total land market price, as agricultural land, of between £698 - 1,037 million.

AGRICULTURAL GRADE LAND	Coastal Corridor		Rest of Cornwall		Cornwall		CC as % of Cornwall
	Area (ha)	% total	Area (ha)	% total	Area (ha)	% total	
Grade 1	116	0.2%	777	0.3%	893	0.3%	13%
Grade 2	9769	16.1%	18340	6.3%	28109	8.0%	35%
Grade 3	37362	61.5%	178017	61.1%	215379	61.1%	17%
Grade 4	6654	11.0%	60574	20.8%	67228	19.1%	10%
Grade 5	1184	2.0%	22119	7.6%	23304	6.6%	5%
Non-Agri	2309	3.8%	8895	3.1%	11204	3.2%	21%
Urban	3311	5.5%	2804	1.0%	6115	1.7%	54%
TOTAL AGRI GRADE	55086		279827		334913		16%
Grade 1 and 2	16.3%		6.6%,		8.2%,		
Grade 3, 4, and 5	74.5%		93.4%		86.9%		

Table 25. Agricultural Grade Land in Cornwall and the coastal corridor (Source: Natural England (2019) Provisional Agricultural Grade Land Classification Maps[94])

	Average £ per ha[95]	Area within the coastal corridor (ha)	Total Estimate £
All Agri Grade land	£ 16,882[96]	41377 ha	£ 698,545,133
	Average £ per ha	Area within the coastal corridor (ha)	Total Estimate £
Grade 1 or 2[97]	£ 22,230	9885	£ 219,743,550
Grade 3	£ 18,525	37362	£ 692,131,050
Grade 4 or 5	£ 12,350	10147	£ 125,315,450
Total			£1,037,190,050

Table 26. Agricultural Grade Land value estimates for the coastal corridor (Source: Savills 2017, 2018; Knight France 2018)

Estimates of the economic significance of agricultural areas within the coastal corridor can also be gauged using estimates of Farm Business Income (FBI). FBI attempts to measure the net profit made by farmers and acts as the main farm level measure of farming income (productivity) (Redman 2018[98]). Specifically, FBI is a measure of the financial return to all unpaid labour (farmers and spouses, non-principal partners and their spouses and family workers) and on all their capital invested in the farm business, including land and buildings or for corporate businesses it represents the financial return on the shareholders' capital invested in the farm business (Redman 2018). FBI per ha varies considerably annually, see Graph 6, and for different farm types. Using FBI is likely to overestimate net profit, as different farm types have different per ha incomes. Average FBI for the SW between 2008/09 and 2014/15 was £323 per ha per annum, compared to an average for England of £338 per ha per annum. Using estimates of average FBI income per ha for the SW (Duchy College 2016[99]) suggests that farming productivity in the coastal corridor could generate up to an estimated £13.36 million in net profit for farmer per annum[100], roughly 15% of total FBI in Cornwall. However, an estimated 67% (or 7.628 million per annum) of this farm income is thought to derive from direct payments (Duchy College 2016).

---

[94] Natural England (2019) https://data.gov.uk/dataset/952421ec-da63-4569-817d-4d6399df40a1/provisional-agricultural-land-classification-alc

[95] Average agricultural land price is estimated from Knight Frank Farmland Index (2018) https://content.knightfrank.com/research/157/documents/en/english-farmland-index-q1-2019-6317.pdf; Savills 2018 Farmland Market Report (2018) https://www.savills.co.uk/research_articles/229130/274008-0.

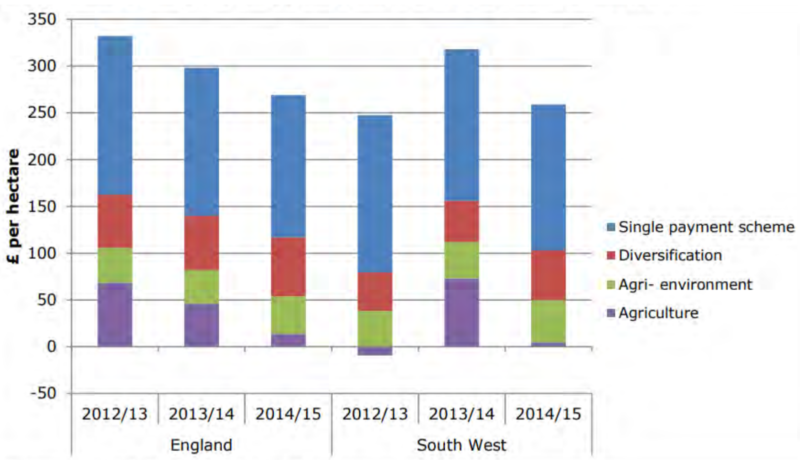
[96] Average £6970 per acre (Knight Frank Farmland Index 2018); Savills (2018) £6970; Average value used £6835 per acres

[97] Average agricultural land price per grade is estimated from Savills (2017) https://www.savills.co.uk/research_articles/229130/228020-0

[98] Redman (2018) John Nix Pocketbook for farm management 2019, 49th Edition, Agro-Business Consultants, Melton Mowbray.

[99] Duchy College (2016) Farm Business Digest - Farm Business Survey https://www.ruralbusinessschool.org.uk/the-farm-business-survey/

*[100] FBI calculation (area of agricultural land * average FBI for the SW (FBS 2012-2015 data))*

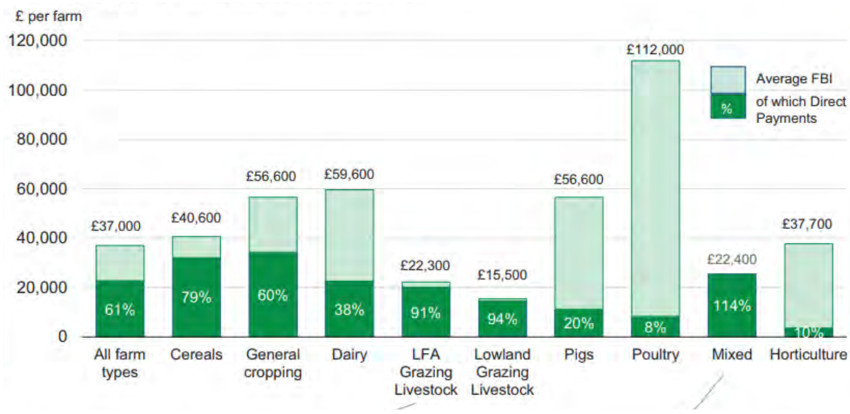


Graph 6. Farm Business Income per ha for England and the SW (Farm Business Survey, Farm Business Digest 2016, Duchy College)

Basic Payment and Agri-Environment Payments

EU payments including Common Agricultural Policy (CAP) Basic Payment (hereafter BPS) tend to form a large part of the profit of agricultural operations. In the SW, BPS is estimated to make up 67% of average Farm Business Income (FBI) (Duchy College 2018[101]), contributing on average around £20,000 per farm/annum. In comparison, across all farm types in England on average 61% of FBI is from BPS (2014/15 and 2016/17). In Cornwall, the average payment received by farms under BPS is thought to be slightly higher at £20,300 per farm/annum (FBS 2019[102]). Analysis by Cumulus Consulting (2017[103]) indicates there are approximately 372 farms with land intersecting, within or close to the coastal corridor. Between them, coastal farmers receive an estimated total BPS of £9,723,000 per year. The vast majority [99%] of land claimed is non-SDA (Severely Disadvantaged Area), i.e. 'lowland' for purposes of BPS. BPS equates to an average of £241/ha, higher than the average for the whole of the SW coastal strip £199.52/ha.

Some farm types are more reliant on BPS (Graph 7). The proportion of income received through BPS is likely to be higher for tenant farmers, an estimated 83% of income (Duchy College 2016). Grazing livestock and mixed farms are also thought to be more reliant on BPS. 19% of UK lowland grazing livestock farms and 22% of mixed farms made a loss including direct payment in 2015-2016, which rises to 53% and 55% respective without direct payments (Defra 2018[104]). Horticulture, pig and poultry farms are considered least likely to be negatively impacted by removal of direct payment. 29% of Cornish agricultural output is linked to lowland grazing livestock, which could mean that the Cornish farming industry is likely to be particularly influenced by changes to BPS under the new Agricultural Bill.



[101] https://www.ruralbusinessschool.org.uk/the-farm-business-survey/
[102] FBS (2019) http://www.farmbusinesssurvey.co.uk/
[103] Cumulus Consulting (2017) The potential impacts of Brexit on the SW Coast land the implications for future agricultural policy, Internal report for the National Trust, unpublished.
[104] Defra (2018) The Future Farming and Environment Evidence Compendium, Online Report, Available at; https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/683972/future-farming-environment-evidence.pdf

Graph 7. Average farm business income and the proportion that comes from Direct payments by 2016 farm type – based on - year matched data set 2014/15 to 2016/17 (Source: Defra 2018[105])

Agri-Environment Schemes, including Countryside Stewardship (CS) and Environmental Stewardship (ES) are estimated to be worth around £53 million to Cornish farmers between 2014-2020 (Cornwall Council 2018[106]). The income received through AES in Cornwall is notably lower than across the rest of the SW (FBS 2018). Farmers in Cornwall are thought to receive less on average through AES than the rest of the SW, with an average AES payment of £2000 per farm/annum compared to £5000 per farm/annum in the rest of the SW (Duchy College 2018). However, AES payments per ha in the coastal corridor are estimated to be similar to other counties (Cumulus Consulting 2017). In Cornwall, CS will deliver £1 million/annum to 225 agreement holders across Cornwall (on average £4,444 per annum/agreement holder), while ES will deliver £6.6 million per annum to 1,130 agreement holders (on average £5789 per annum/agreement holder). The Cornwall Futures Group (2018[107]) and Cornwall Council (2018[108]) suggest that the limited uptake of Countryside Stewardship (CS) is due to the limited land management options available, unattractive payment rates, a lack of appreciation of fit with the land management practice in Cornwall, and costs outweighing time taken to apply and manage CS contracts. There are an estimated 253 AES agreement holders with land intersecting the coastal corridor (CS and ES combined), including approximately 60 CS agreement holders and 193 ES agreement holders. AES agreements cover a total area of some 13,916 ha, with a total annual value to agreement holders of £1.597 million, with an average payment of £115/per ha. In comparison to other areas in the SW coastal corridor, Cumulus Consulting (2017) find that Cornwall benefits from the highest total annual cost (payment), although Dorset has the highest unit annual cost (payment per ha).

	No of agreements	Total Area (HA)	As % of total area	Total annual cost of agreements portioned with Coastal Corridor	Unit annual Cost of Agreement (£/ha)
Coastal Corridor	253	13,916	32.9%	£1,597,944	£115

Table 27. Agri-Environment Schemes in the Coastal Corridor (Cumulus Consulting 2017)

Horticulture and arable

The geography and climate of Cornwall give it a distinct advantage in horticultural production, with a longer and an earlier growing season than many parts of the UK. Within the SW, Cornwall is the largest producer of potatoes and brassicas. Cornwall also produces flowers, with daffodils being the most significant flower and flower-bulb crop. Notably, flower production has increased in Cornwall against a backdrop of declining production across England. Data on primary production in the horticulture sector is not readily available. Defra records just one crop per field per year, whereas in reality that same field may be used for growing two or more crops, particularly in Cornwall with the extended season. Crop maps therefore only provide a limited picture of crop types grown in the coastal corridor (e.g. CROME[109] or LCM 2017 plus Crop[110]).

Spatial data from the LCM 2017 Plus Crops map (CEH 2017), clipped to the coastal corridor, suggest that the crops covering the largest areas of the coastal corridor include spring barley, maize, winter wheat and oats and winter barley (Table 28). The profile of crops grown in the coastal corridor is similar to the rest of Cornwall. The value of these different crop types has been broadly estimated using average yield per ha, and average gross margins per ha (Redman 2018). Gross margins (GM) provide a measure of an enterprise's output less its variable costs. GMs are not, however, a profit figure as fixed costs or overheads have not been subtracted, and these still need to be covered before arriving at a profit figure. Fixed costs vary significantly based on farm structure, season, labour, machinery, rent, general overhead, soil, geography, climate etc, using a blanket fixed cost is therefore not advised by Redman (2018). Crops such as potatoes, maize and spring barley are thought to have higher average gross margins per ha, when combined with area under each crop type this suggests that spring barley, maize, winter wheat and oats and winter barley contribute the most in terms of agricultural productivity of crop areas. Based on GM per ha, the productivity of the crop areas in the coastal corridor is estimated to be between £8,952,847 and £17,905,694 per year, this range in value is given as the CEH crop map provides data on only one crop type per year whereas most fields will produce a secondary crop. Particularly high productivity crops for the CC include field beans, maize and spring barley, winter wheat and oats and other crops (i.e. rye, fruit, flowers, pea etc.), whilst for the rest of Cornwall potatoes, winter wheat and oats have a higher percentage share than in the coastal corridor.

[105] *Defra (2018) The Future Farming and Environment Evidence Compendium, Online Report, Available at;* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/683972/future-farming-environment-evidence.pdf
[106] https://www.cornwall.gov.uk/media/35785823/defra-consultation-final-submitted-response-4th-may-2018.pdf
[107] https://www.cornwall.gov.uk/media/24227365/catalyst-for-change-brexit-report.pdf
[108] https://www.cornwall.gov.uk/media/35807050/new-frontiers-2018_part_2.pdf
[109] *CROME Crop Map of England (2017)* https://data.gov.uk/dataset/e2f5de8d-a46e-4c8b-800d-3375cf19ad57/crop-map-of-england-crome-2017-north
[110] *CEH (2017) Land Cover Map Plus Crops 2017*

	Coastal corridor (Ha)		Cornwall (Ha)		Avg. yield tonnes per ha	CC Yield tonnes	Cornwall Yield tonnes	Avg. gross margins per ha	CC Agricultural productivity	Cornwall agri productivity
Field beans	275	2.6%	792	1.7%	4	1113	3209	£472	£129,706	£374,043
Maize	1442	13.8%	6374	13.5%	8	10818	47806	£884	£1,275,082	£5,634,677
Oilseed rape	314	3.0%	1094	2.3%	3	880	3062	£589	£185,123	£644,149
Other crops	3000	28.6%	13599	28.9%	7	22019	99815	£944	£2,831,906	£12,837,220
Potatoes	472	4.5%	2669	5.7%	45	21254	120087	£1534	£724,508	£4,093,640
Spring barley	2320	22.1%	9423	20.0%	6	13226	53710	£895	£2,076,758	£8,433,396
Spring Wheat	137	1.3%	713	1.5%	6	834	4349	£615	£84,071	£438,462
Winter barley	1195	11.4%	5227	11.1%	7	8124	35545	£592	£707,262	£3,094,494
Winter wheat & oats	1324	12.6%	7176	15.2%	7	9477	51381	£709	£938,432	£5,087,874
TOTAL	10479		47067			87745	418964		£8,952,847	£40,637,955

Table 28. Agricultural productivity of crops in the coastal corridor (Sources: Yield per tonne Defra 2017; Rural Business Survey; Defra June Survey, AHDC, Environmental Valuation Lookup Tool, Redman (2018)[111]

Grazing and Livestock

The coastal corridor has a considerably lower percentage cover of grazing areas (improved grassland) (25%) compared to the rest of Cornwall (51%). There is an estimated 78,000-79,000 livestock within the coastal corridor, including cattle and sheep. Livestock numbers were estimated based on the June Defra survey of total livestock numbers across Cornwall. Based on gross margin per ha, after forage costs, the agricultural productivity of livestock in the coastal is estimated to be around £14.45 million to £17.56 million per year[112], however, these figures have not been adjusted to account for fixed costs such as labour, rent etc.

Agri-food processing

The agri-food sector handles the secondary processing of agricultural products. 45% of Cornwall's manufacturing and wholesaling employment is in agri-food and drink processing, compared to only 21% in the UK. 3.2% of people in Cornwall are employed in the manufacture of food products and drinks in Cornwall, a higher proportion than across the SW (1.4%) and England (1.3%) (Cornwall Council 2012). In Cornwall, the agri-food industry is involved in the processing and preserving of meat, the production of meat products, the manufacture of bakery and flour-based products (confectionary) and the manufacture of dairy products (with one of the largest cheddar cheese production facilities in Europe). Dairy products have become more important in recent years (such as Davidstow Cheddar and Cathedral Cheddar). As a share of the economy, food and drink manufacturing contribute around 3% to Cornwall's GVA. The agri-food industry is reportedly increasingly interested in alternative energy sources and environmental sustainability (Lobley et al 2011). In 2017, there was an estimated 205[113] agri-food business across Cornwall (not including food services or hospitality) (Cornwall Futures Group 2017[114]), 24% of these businesses were involved in the production of confectionery, 15% breweries, and 7% meat processing.

The agri-food industry is spatially distributed across Cornwall with no identifiable concentration in the coastal corridor. Some of the major agri-business employers in Cornwall include Samworth Brothers, Dairy Crest, Milk link, Rodda's and FalFish. The beverage sector is wide-ranging (bottling water, microbreweries, large-scale breweries) (annual turnover of businesses range from £200,000 to £20m) (Lobley et al. 2011[115]). A number of major breweries operate across Cornwall, which have expanded over the last decade (Lobley et al. 2011). Major breweries including Skinners, Atlantic Brewing, Sharp's Brewery and St Austell Brewery. Many of Cornwall's breweries are located close to the coastal corridor, including 24% (8) within the coastal corridor, and 42% (14) within 4km of MHW (Appendix X). Many breweries have a notable focus on quality, and want to maintain their Cornish credentials for marketing purposes (Lobley et al. 2011).

---

[111] *Source Yield per tonne: Defra 2017, State of Agriculture in the UK https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/741062/AUK-2017-18sep18.pdf Source: Gross Margins Rural Business Survey, Defra June Survey, AHDC, Environmental Valuation Lookup Tool Defra Av gross margins per ha: Redman (2018)*

[112] ***Cornwall** -; Improved grassland CUA = 169406.1 ha, SNGI: 14874 ha; Total number of cattle = 323,146; Total number of sheep = 506,588.CUA Stocking rate 4.5 per ha (sheep or cattle). CUA Total livestock 829734. **Coastal Corridor,** Improved grassland = 16321 ha; SNG = 766 ha'; Total grazing areas = 17087 ha; Total estimated cattle/sheep in the coastal corridor 78,891.5. (Stocking rate 4.5 per ha * 17087 ha). Gross margin per ha after forage costs: Dairy cows average (£2231); Beef: Suckler cowers: lowland (£149); Sheep; lowland spring lamb (grass) (£158); Total CC livestock: 78,891.5 (cattle 38%) (sheep 62%); Total CC cattle: 29,978 ; Total CC sheep: 48,913; Gross margin per ha after foraging cost (Grazing land equally divided between 3 livestock types); Dairy = 5695 ha * Dairy cows average (£2231); = £12,707,032; Beef = 5695 ha* Suckler cows: lowland (£149); = £848,555; Sheep = 5695 ha * lowland spring lamb (grass) (£158) = £899,810; Total Gross Margin - Livestock = £14,455,397 per year. Alternative approach* Assume all improved grassland is dairy/beef; all SNGI spring lowland lambs; Estimated population cattle 31,009.9 (stocking rate 1.9); Estimate population sheep 26,427 (stocking rate 34.5); Gross margin per head Lowland spring lamb (£21) £554,967; Dairy (£1014) = £15,721,563; Beef (£83) = £1286,873.5; Total = £17,563,403.5. Estimate value between 14.45 million and 17.56 million per year *All gross margins from Redman (2018)*

[113] *Out of date – 2017 figures Lobley et al. 2011.*

[114] https://www.cornwall.gov.uk/media/32528517/new-frontiers-2018.pdf; https://www.cornwall.gov.uk/media/24227365/catalyst-for-change-brexit-report.pdf

[115] *Lobley et al. (2011) A review of Cornwall's Agri-Food Industry: Final report, CRPR Research Report No 32, available at: https://socialsciences.exeter.ac.uk/media/universityofexeter/research/microsites/centreforruralpolicyresearch/pdfs/researchreports/Cornish_food_economy_final_report_FINAL.pdf*

3.03.03 Forestry

- *The Forestry Sector is relatively small in Cornwall, and the coastal corridor is not thought to be particularly significant for this sector. The coastal corridor contains only a very small proportion of coniferous woodlands in Cornwall, 200-400 ha (approx. 6%). However, there is an area of 352 ha of young trees planted in the coastal corridor, which represents an estimated 23% of the total area of young trees across Cornwall.*
- *Only one timber processing site lies within the coastal corridor, Cornish Wood Fuels, however Truro Sawmills lies close to the coastal corridor close to Perranporth.*
- *Between 1997 and 2016 there were 739 applications for a felling licence in Cornwall, covering an area of 3741 ha, these felling licence applications cover an area of 568 ha within the coastal corridor (15% of total felling licence area). Felling applications in the coastal corridor were mainly concentrated along the south coast, main locations of felling within the coastal corridor include (1) Lynher river/St German, (2) R.Tamar near Tremarn, (3) Cotehele Mill, (4) Trelawn/East Looe River, (5) Charlestown, (6) Tresillian, (7) Mawgan/Trelowarren, (8) Treworder Wood.*

Forestry is often a key component of rural economies. Many areas of woodland are still valued primarily on their timber value, as a raw resource for the creation of wood-based products or in terms of wood fuel for the generation of renewable heat and electricity. Agriculture, forestry and fishing is the largest industry group (by enterprise count) in Cornwall, however commercial forestry has not historically been a key part of this sector in Cornwall. At 9.57% the woodland cover in Cornwall is slightly below the percentage coverage for England [10%] and the UK cover [13%]. Much of Cornwall's woodland is thought to be owned and managed by the Forestry Commission (10%), National Trust, Cornwall Wildlife Trust, Cornwall Council, The Woodland Trust and the Duchy of Cornwall. The commercial plantation forestry in Cornwall is not concentrated in the coastal corridor but instead in the east around Bodmin Moor and along the A38 east of Bodmin. There are five timber processing sites in Cornwall including sawmill, fencing and pellet production (St Teath Sawmills, Branston, Truro Sawmills, Rawnsley Wood Products and Cornish Wood Fuel). These sites also process wood for wood fuel for the generation of renewable heat and electricity. Only one timber processing site lies within the coastal corridor, Cornish Wood Fuel, however Truro Sawmills lies close to the coastal corridor close to Perranporth. Notably, there is only a very small proportion of coniferous plantation within the coastal corridor, some 200-400 ha (depending on the data set used), compared to the 4000-5000 ha of coniferous woodland in the whole of Cornwall. Coniferous woodland in the coastal corridor accounts for only around 4-8% of total coniferous woodland in Cornwall. However, there is around 352 ha of young trees planted in the coastal corridor, which represents an estimated 23% of the total area of young trees across Cornwall.

Over half of the woodland in the SW is not thought to be in active management. Hölzinger and Laughlin (2016[116]) suggest that total harvesting levels across the AONB, which covers much of the coastal corridor, have not changed significantly between 1995 and 2015. There is no comprehensive map of commercially managed forestry nationally or regionally. Between 1997 and 2016 there were 739 applications for felling licences in Cornwall covering an area of 3741 ha, with applications covering an area of 568 ha made within the coastal corridor (15% of total felling licence area). Felling applications in the coastal corridor were mainly concentrated along the south coast, with main locations of felling including (1) Lynher river/St German, (2) R.Tamar near Tremarn, (3) Cotehele Mill, (4) Trelawn/East Looe River, (5) Charlestown, (6) Tresillian, (7) Mawgan/Trelowarren, and (8) Treworder Wood.

NFI	Cornwall CC		Cornwall UA		CC as % of total CUA area
	Area *ha	% total area	Area	% total area	
Assumed woodland	143	2.3%	572	1.7%	25%
Broadleaved	5,107	81.5%	23,669	71.7%	22%
Conifer	403	6.4%	5,104	15.5%	8%
Coppice	-	-	3	0.0%	-
Failed	-	-	67	0.2%	-
Felled	27	1.1%	736	2.2%	4%
Ground prep	66	0.5%	144	0.4%	46%
Low density	28	0.9%	153	0.5%	18%
Mixed mainly broadleaved	56	1.3%	472	1.4%	12%
Mixed mainly conifer	79	0.0%	506	1.5%	16%
Windblow	2	5.6%	8	0.0%	25%
Young trees	352	1.1%	1,563	4.7%	23%
TOTAL	6,263		32,996		18.9%

[116] *Hölzinger and Laughlin (2016) Cornwall Area of Outstanding Natural Beauty Natural Capital Assessment, Main Report, The Cornwall AONB Unit, Truro, https://static1.squarespace.com/static/54e6ffe7e4b0663b4a777e12/t/5892fb04725e25be04c61e3d/1486027528048/CAONB+NCA+Main+Report+Final+Feb+2017.pdf.*

Table 29. National Forest Inventory: the location and extent of all forests and woodlands (0.5 hectares and over) in the coastal corridor and Cornwall (Source Forestry Commission/Forest Research[117])

3.03.04 Fisheries and Aquaculture

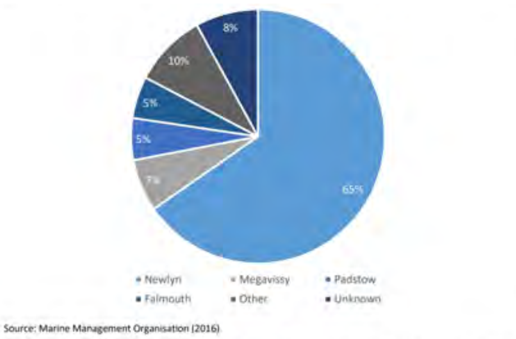
Fisheries

➢ *Total landed value of the fisheries sector in the Cornwall is approximately £23.5 million*.

Cornish fish stocks are diverse with a range of 40-50 commercial species, those species contributing the most value include monks or anglers, megrim, pollack, edible crab, cuttlefish and scallops (Cornwall Council 2012[118]). The commercial and recreational fishing industry plays a role in both the Cornish economy and the historic cultural identity of Cornwall's coastal villages, ports and harbour towns (**ibid*). The main commercial fishing centre in Cornwall is in Newlyn, with 581 registered boats. Recreational angling is also of increasing economic importance to Cornwall, with links to the tourism industry. Most sections of Cornwall's fishing fleet are currently economically viable. However, many of the larger vessels face difficulties. The fleet is increasingly specialised, reducing the flexibility of vessels to fish for different species or use different gear types, and this means that vessels become less able to adapt to natural fluctuations in abundance of fish stocks. As much of Cornwall's catch is exported, the fisheries sector, similar to agriculture, is likely to be significantly impacted by Brexit, with areas of concern including demand for labour and business viability, future fisheries policies and subsidies, access to fishing grounds and stock quotas, environmental legislation and trade agreements.

Landing Port	Landed Weight (Tonnes)	Most Common Species	Total Landed Value (£) (2009)
Newlyn	7,120.76	Monks, Sole, Megrim, Scallops, Crab	£17,243,104
Looe	774.80	Lemon Sole, Monks, Scallops, Squid	£1,788,242
River Fal	809.73	Scallops, Anchovy, Monks	£1,606,896
Mevagissey	713.39	Pollack, Scallops, Mackerel	£1,458,926
Padstow	473.78	Lobsters, Crab, Turbot	£1,438,771
		TOTAL	£23,535,939

Table 30. Fish stocks, species and landing value in Cornwall (Source: Ports in Cornwall with highest value catch (2009) (Marine Management Organisation 2009))



Graph 8. Spread of fishing vessels of over 10m in length across Cornwall (Source: Cornwall Council 2016/Marine Management Organisation 2016)

Aquaculture

➢ *The aquaculture industry has a total landed value of £4.2 million. At some locations, the development of the aquaculture industry has also been directly influenced/constrained by the coastal corridor due to the dependency of aquaculture on pristine water quality. At present only 26% of estuaries and 44% of coastal areas are assessed as being of good ecological quality which limits the capacity of aquaculture to develop close to the coastal corridor.*

Cornwall's sheltered bays and estuaries provide ideal environments for aquaculture farming of a range of species. Globally, aquaculture is the fastest growing sector of the food production industry. The aquaculture industry encompasses a range of activities, from rope grown mussels to farmed fish. The Cornish aquaculture industry is relatively undeveloped but has grown over the last decade. The main aquaculture activities in Cornwall include shellfish/bivalve farming of mussels or oysters with estuaries or nearshore coastal waters. There is also a small amount of finfish farming, and lobster stocks (e.g. the National Lobster Hatchery). Some aquaculture sites are located close to the coastal corridor, including the Duchy of Cornwall Oyster farm situated on the Helford

---

[117] https://www.forestresearch.gov.uk/tools-and-resources/national-forest-inventory/

[118] Cornwall Council (2012) A future for maritime Cornwall: The Cornwall Maritime Strategy 2012-2030, Annex: Background Info https://www.cornwall.gov.uk/media/3623049/Annex-background-information-2-.pdf

River, St Austell Bay and the Fal, Helford and Fowey estuaries are the main sites of a Cornish rope-grown mussel industry (Westcountry Mussels of Fowey (Shellfish breed ground)), and the National Lobster Hatchery in Padstow, while the Cornish Seawood company are trial growing plants on ropes at another one of its sites, farther west at Porthallow.

At some locations, the development of the aquaculture industry has also been directly influenced/constrained by the coastal corridor due to the dependency of aquaculture on pristine water quality. At present only 26% of estuaries and 44% of coastal areas are assessed as being of good ecological quality (Cornwall Council 2015[119]) which limits the capacity of aquaculture to develop close to the coastal corridor. Indeed, fluctuating water quality poses issues for aquaculture particularly in estuaries and harbours, and this has led to decisions to move aquaculture off-shore, as water quality is often much higher in bays than in estuaries, linked to storm events.

3.03.05 Mining or Quarrying

- *According to the GeoIndex Onshore (2019), there are 50 active mines and quarries, 26% [13] of these are sited within or very close to the coastal corridor.*

Mining or quarrying has a raw Gross Value Added (GVA) to the Cornish economy of around £30 million per year (2010-2012 average). The Cornish mining industry is a key part of the Cornwall historic landscape and Cornish identity, although many mines are inland there are several important heritage mines in coastal locations, including the Port of Hayle, the St Just and St Agnes Mining Districts and Charlestown Harbour. Although the total number of jobs in mining and quarrying across Cornwall is relatively modest (just over 1000) it is five times more than is typical across the rest of England. At present, there are approximately 50 active mines and quarries across Cornwall (GeoIndex Onshore 2019[120]). The extraction of china clay continues to be of considerable importance: the larger works are in the St Austell district. Granite of high quality has been extracted from many Cornish quarries such as De Lank and Porthoustock. In 2017, plans were reported to extract lithium reserves from beneath Cornwall by Cornish Lithium, who had signed agreements to develop potential deposits. Thirteen currently active quarries and mines lie within or very close to the coastal corridor (26% of total). However, only 0.4% of the resident population of the coastal corridor is employed in mining or quarrying industries (ONS 2011).

Active Quarries or Mines	Quarry Type	Distance from MHW	Turnover
Yelland Wharf	Crushed Rock	0.3km	Unknown
Middle Dock	Marine Sand and Gravel	0.1 km	Unknown
Appledore Wharf	Marine Sand and Gravel	0.08 km	Unknown
Beam Quarry	Sandstone	6.9 km	Unknown
Trevillet Quarry	Slate	1.75 km	Unknown
Trebarwith road Rustic	Slate	2.52 km	Unknown
Trecarne Quarry	Slate	1.82 km	Unknown
Tynes Quarry	Slate	1.41 km	Unknown
Blue Hills Tin Streams	Tin	0.51 km	Unknown
Beacon Pit	Clay and Shale	0.72 km	Unknown
Lizard Workery	Serpentine	1.46 km	Unknown
West of England Quarry	Igneous and Metamorphic Rock	0.17 km	Unknown
Porthkerris Sea Salt Plant	Sea Salt	0.02 km	Unknown

Table 31. Active quarries or mines within or near the Coastal Corridor

3.03.06 Construction and Real Estate

- *The coastal corridor is a focal point for real estate development. Cornwall Site Allocations Development Plan Document (Allocations DPD) identifies where new housing and employment uses are planned. Based on the Site Allocation Development Plan, 36.4% of all 'allocation sites' (by area) lie within or intersect the coastal corridor. Based on estimated dwelling numbers for housing based allocations, 49.5% of allocated dwellings will be in sites which intersect or lie within the coastal corridor.*

The coastal corridor is a focal point for real estate development. 32-37% of the population of Cornwall is already thought to be resident in the coastal corridor, with predicted growth in population levels of 9.15% by 2030. Residential property prices within the coastal corridor are estimated to be around 27% higher than the average for the whole of Cornwall. Cornwall's Site Allocations Development Plan Document (Allocations DPD), published in 2017/early 2018, identifies where new real estate (housing development) and employment uses will be delivered in Cornwall. Planned site allocation shows that 36.4% of allocation sites lie

[119] *Cornwall Council (2015) Environmental Growth Strategy.*
[120] *GeoIndex Onshore (2019) http://mapapps2.bgs.ac.uk/geoindex/home.html?layer=BGSMinAM*

within or intersect the coastal corridor. Based on estimated dwelling numbers per site 49.5% of allocated dwellings will be in sites which intersect or lie within the coastal corridor.

Allocations	Coastal Corridor	Cornwall	CC % of total allocation
Estimated Site Area (ha)	*296*	*814*	*36.4%*
Estimated Dwelling numbers	*6,101*	*12,315*	*49.5%*

Table 32. Cornwall Site Allocation Spatial Plan and the coastal corridor (Source: Cornwall Council[121])

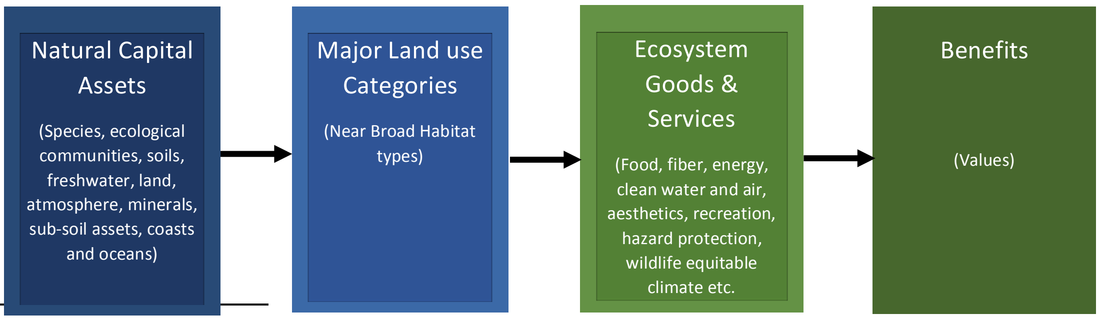
4. ENVIRONMENT CHARACTERISTICS

4.01 NATURAL CAPITAL

Natural Capital Assets are the elements of the natural environment which provide valuable ecosystem goods and services to people (see figure 1), including species, ecological communities, soils, freshwater, land, atmosphere, minerals, sub-soil assets, coasts and oceans (Natural Capital Committee 2013, 2014, 2019[122]). A natural capital asset register, or portfolio, provides an inventory of all of the natural capital assets present in an area, a means to understand the potential of an area to deliver flows of ecosystem goods and services and a baseline to inform the possible trade-offs (Natural Capital Committee 2015[123]).

Natural capital asset registers can be compiled using broad habitat types (land use categories) as proxies for ecosystems (Natural Capital Committee 2015[124]). Although using broad habitat types is a practical approach it must be acknowledged that it is also limited, as it does not measure the actually delivery of ecosystem goods and services (e.g. Burkhard et al., 2012[125]). The capacity of natural capital assets to deliver ecosystem goods and services is thought to be influenced by three key factors: (1) the extent or quantity (geographic area) of the asset, (2) its condition or quality, and (3) its spatial configuration (Natural Capital Committee 2015; Mace et a 2015[126]; See table 33).

To assess the natural capital assets present in the coastal corridor, the extent and type of broad habitats present has been estimated using the National Landscape Cover Map (CEH 2015[127]) (Table 34). Spatial data on the condition of broad habitat types is not widely available. Instead, monitoring data on the condition of Sites of Special Scientific Interest (SSSI) has been used as a proxy to provide some estimate of the condition of broad habitat types (Natural England 2019[128]). This use of SSSI condition data was justified by Mace et al. (2015) "*on the basis that, although targets for SSSIs are likely to be more stringent, equally their protected status should mean that there is greater emphasis on securing the right management. Overall, we would expect SSSI land to be in a better state than non-SSSI land in a similar habitat category, and hence, our assumption is likely to be conservative*" (Mace et al. 2015). Spatial configuration has been estimated from local and national reporting where available. Information on the extent, condition and spatial configuration has been assessed using the RAG (red, amber, green) criteria (see Table 34) in relation to national and local targets, and national and local trends (Mace et al. 2015).



[121] *https://www.cornwall.gov.uk/media/21956015/dpd-whole-document-v2.pdf; https://www.cornwall.gov.uk/environment-and-planning/planning/planning-policy/examinations-201718/cornwall-site-allocations-dpd/cornwall-site-allocations-dpd-examination-position-statements/*
[122] *Natural Capital Committee https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/516698/ncc-state-natural-capital-second-report.pdf; https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/774218/ncc-annual-report-2019.pdf*
[123] *Natural Capital Committee (2015) How to do it: a natural capital workbook, Version 1, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/608852/ncc-natural-capital-workbook.pdf*
[124] *Natural Capital Committee (2015) How to do it: a natural capital workbook, Version 1, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/608852/ncc-natural-capital-workbook.pdf*
[125] *Burkhard et al. (2012) Mapping ecosystem service supply, demand and budgets. Ecological Indicators 21: 17-29*
[126] *Mace et al. (2015) Towards a risk register for natural capital, Journal of Applied Ecology 52: 641-653.* https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/1365-2664.12431
[127] *CEH (2015) https://www.ceh.ac.uk/services/land-cover-map-2015*
[128] *Natural England (2019) Sites of Special Scientific Interest Units (England) Attribution statement: © Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right [year]. Attribution statement: Attribution statement: © Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right [year] https://data.gov.uk/dataset/c52ead19-47c2-473b-b087-0842157e00b6/sites-of-special-scientific-interest-units-england*

Figure 1. A framework linking natural capital and benefits to people (Source: Natural Capital Committee, 2014, 34).

Type of Asset		What is it?	How will it be assessed
Stock of assets	Extent	How much?	GIS data (polygon/polyline). National Land Cover Map (CEH 2015). Expanding or decreasing
	Condition	What state is it in?	Categories and national or local targets (1) Biodiversity Strategy 2020 (2) 25-year Environment Plan. Improving or declining
	Spatial configuration	Where is it?	Local or national reporting on spatial configures of broad habitat types. Improving or declining

Table 33 Natural Capital Asset Assessment

	STATUS			
TREND		Above, at or just below target	Below target (>10%<30%)	Substantially below target (>30%)
	Positive or not discernible	A	B	B
	Negative	B	B	C
	Strongly negative	C	C	C

Table 34. Red, Amber, Green Key (A = Above at or just below target <10%; B = below target >10% to 40%; C = Substantially below target 40%) (Mace et al. 2015)

Natural Capital Assets in the coastal corridor

A wide range of semi-natural habitats, natural capital assets, are present across the coastal corridor. The coastline itself ranges from an extensive network of indented coves, long river estuaries and creeks, to exposed headlands, sheer cliffs and large sandy beaches. The nature of the coastline differs significantly between the north and south section of the peninsula. The northern Atlantic coastline is exposed to prevailing SW and NW winds, with sheer cliffs, steep valleys and extensive dunes, while the more sheltered southern coast, facing the English Channel, comprises of a series of tree-lined estuaries intersected with headlands, cliffs and sheltered beaches. Habitats along the Cornish coastline range from sand dunes to vegetated shines, beaches, saline lagoons, and salt-marshes. The coastline already forms an essential ecological network, with particular importance for migrant birds and shorebirds, and a significant area designated as Sites of Special Scientific Interest (SSSIs) and as an Area of Outstanding Natural Beauty (AONB). Moving inland from the coastline, the coastal corridor contains a range of habitats, from sheltered broadleaved wooded estuaries, to exposed coastal heathlands and semi-natural grassland, often with abrupt transitions into agriculturally improved grasslands, horticultural and arable areas, urban and suburban settlements.

In total, natural capital assets are estimated to cover 87% of the coastal corridor [56,300 ha]. Looking at the coastal corridor as a whole indicates that, in terms of percentage area, the vast majority of the corridor consists of enclosed grasslands, much like the rest of Cornwall. These enclosed agricultural grasslands, including arable and horticultural areas and improved grasslands, cover some 73% of all natural capital assets in the corridor and some 64% of the total area of the corridor. Only two other major natural capital assets groups cover significant percentage areas of the coastal corridor, woodlands (13%) and coastal margins (9%). All other habitats, including moors and heaths, semi-natural grasslands, fens, marshes and swamps, and freshwater habitats, have a percentage area under 5% of the coastal corridor. Comparing the coastal corridor to the rest of Cornwall shows that it has a notably lower proportion of enclosed grassland (agricultural areas) (-5%), and semi-natural grasslands (-4%), and a notably higher percentage are of woodlands (+3%) and, as to be expected, coastal margin habitats (+6%).

By area, 95% of natural capital assets in the coastal corridor consist of enclosed grasslands, woodlands and coastal margin habitats, these habitats are associated with the delivery of certain priority ecosystem goods and services. Woodlands have the potential to deliver the largest range of ecosystem services, however, coastal margins may provide the most valuable services through leisure and hazard and climate regulation, while by virtue of their extent enclosed grasslands have significant potential for improvement in ecosystem service delivery. In terms of condition, based on SSSI data for the SW, moors, heath and bog and enclosed grasslands have the lowest percentage area in favourable condition, closely followed by semi-natural grasslands (SNG) and fen, marsh and swamp, while freshwater habitats and coastal margins have the highest percentage area in favourable condition (Natural England

2019). Both moors and heaths and enclosed grassland habitats have suffered from both short and long term decrease in extent, while woodlands and freshwater habitats have seen gains in the short term (since 1995). A risk rating approach (assessed in Table 36 and sections 4.01.01 to 4.01.07) shows that enclosed grasslands are most at risk in terms of extent and condition, while woodlands, moors and heaths and coastal margins have performed the best. However, this assessment was performed with limited data on local and national extent changes and quantity targets which could change this assessment in the future, along with updated Natural England SSSI data expected in 2019/2020.

Broad Habitat Type	Coastal Corridor Area (Ha)	Coastal Corridor %	Rest of Cornwall %
Woodland	7,119	13%	10%
Enclosed Grassland	41,377	73%	79%
Semi-Natural Grassland	766	1%	5%
Moors or Heaths	1,826	3%	3%
Fen, Marsh or Swamp	27	0.01%	0.02%
Coastal Margins	5,124	9%	3%
Freshwater	81	0.1%	0.4%
TOTAL	56,320		

Table 35. Broad habitat types in the coastal corridor and the rest of Cornwall (Source: LCM CEH 2015)

	Condition		Extent	
	Favourable	Favourable and recovering	Short term (post-1995)	Long term (since the 1900s)
Moors and heath	19%	95%	Decrease	Decrease
Enclosed grasslands	20%	63%	Decrease	Decrease
Semi-Natural Grassland	38%	89%	Minor loss	Decrease
Fen, marsh or swamp	39%	75%	Minor Loss	Decrease
Woodlands	46%	92%	Gain	Increase
Freshwater	55%	68%	Gain	Decrease
Coastal margins	82%	95%	Stable/minor loss	Decrease

Table 36. Broad habitat types by condition and extent for the coastal corridor

Broad Habitat Type			
	Quantity	Quality	Spatial Configuration
Woodland	A	B	B
Enclosed Grassland	C	C	B
Semi-Natural Grassland	B	B	B
Moors or Heaths	B	A	B
Fen, Marsh or Swamp	B	C	B
Coastal Margins	B	A	B
Freshwater	B	C	B

Table 37. Broad habitats by risk rating for the coastal corridor (spatial configuration is largely unassessed)

4.01.01 Enclosed Farmlands and Grasslands

Enclosed farmlands and grasslands, including arable and horticultural areas and improved grassland, account for an estimated 73% of the area of natural capital assets in the coastal corridor [41377 ha], and 64% of the coastal corridor. The coastal corridor has a notably higher percentage area of arable and horticultural land than the rest of Cornwall (Table 35). Across Cornwall, the extent of enclosed farmlands and grasslands is thought to have declined between 1995 and 2005 by 1900 ha (ERCCIS 2009[129]). However, the Cornwall AONB (CAONB) Natural Capital Report (2015), which covers 65% of the coastal corridor, highlights a loss in the area of enclosed grassland of 365 ha between 1995 and 2005 (-0.7%) mainly due to afforestation.

The condition of enclosed grasslands across the SW is thought to be relatively poor with only just 63% in favourable or unfavourable but recovering condition, -55% departure from the 25-year environment plan target for 75% of enclosed grassland habitats to be in favourable condition by 2030 (Natural England 2019). Nationally, species indicators suggest that the capacity of enclosed farmland and grassland to support biodiversity has fallen considerably since the 1970s, with a 48% drop in the 19 specialist farmland birds recorded by the RSPB between 1970 and 2018 (RSPB 2019[130]). The NEA (2011) also records a national decline in the diversity of enclosed farmlands, including a reduction in the number of ponds, length of hedgerows and area of farm woodlands. However, there are 253 active AES agreements within or close to the coastal corridor, designed to improve the condition of 13,914 ha of enclosed grasslands in the coastal corridor (32.9%) for biodiversity and related ecosystem services benefits, with annual value to farmers of £115 per ha (See Section 3.04.02).

Enclosed grasslands and farmlands are linked to the provision of ecosystem services including food production. Across Cornwall, 6% of GVA is linked to the agri-food sector, while the coastal corridor contains one-third of Cornwall's best and most versatile (grade 1 or 2) agricultural land, with particular importance for arable and horticultural farm types. Enclosed grasslands not only deliver economic returns via agricultural production but also cultural services, including heritage, recreation and sense-of-place. However, focusing solely on the delivery of provisioning services has the potential negatively to affect a number of other ecosystem services, including the provision of clean water, habitat for wildlife, climate regulation and hazard protection (NEA 2011). Certain food production practices have also resulted in soil erosion and carbon loss, biodiversity loss and greenhouse gas emissions. Recent agricultural practices have also seen major declines in specialist farmland species[131]. Enclosed grasslands and farmlands already help to manage water quantity but this capacity could be further enhanced through changes in land-management practice and habitat creation. Changes in agricultural land management practices could also be used to enhance the potential to deliver services, including climate regulation, clean water, hazard regulation and supporting biodiversity.

Characteristic	Current Status	Target	Trend
Quantity	41,377 ha *60% arable and horticultural areas, 40% improved grassland (CEH 2015).*	No target	Between 1995 and 2005, the area of enclosed grassland in Cornwall declined by 1900 ha (ERCCIS 2009). The decline in enclosed grassland areas represents the largest land cover change across Cornwall recorded by the ERCCIS land cover change project (2009). The Cornwall AONB (CAONB) Natural Capital Report (2015), which covers 65% of the coastal corridor, highlights a loss in the area of enclosed grassland of 365 ha between 1995 and 2005 (-0.7%) mainly due to afforestation.
	B (Unknown)		C (Strongly Negative)
Quality	By area, 63% SSSI in this broad habitat type are classed as favourable/ unfavourable recovering (NE 2019). *43% unfavourable recovering; 20% favourable*	≥95% SSSI favourable/ recovering by 2020 (Biodiversity Strategy 2020) ≥75% of terrestrial and freshwater protected sites to favourable condition (25 Year Environment Plan 2018)	63% of enclosed grassland SSSI in the SW are in favourable or unfavourable recovering condition, -32% from the 2020 biodiversity strategy target. 20% are in favourable condition, -55% from the 25-year environment plan target. Nationally there has been an increase in agri-environment scheme (AES) and payments under CAP, AES payments per ha in the coastal corridor are estimated to be similar to other SW counties (Cumulus Consulting 2017). Nationally the numbers of specialist farmland birds had fallen to 40% of their 1970 levels in 2000, and they have fallen a further 4% since then (UK NEA, 2011). The arable farmland bird indicator shows that overall average change for the 19 species is a 48% decline since 1970 (RSPB 2019[132]).
	B (substantially below target)		C (strongly negative)

[129] *ERCCIS (2009) Land cover report https://www.google.com/search?q=ERCCIS+2009+land+cover+change&oq=ERCCIS+2009+land+cover+change&aqs=chrome..69i57.2973j0j4&sourceid=chrome&ie=UTF-8*
[130] *RSPB Farmland Bird Indicator: https://www.rspb.org.uk/our-work/conservation-and-sustainability/farming/near-you/farmland-bird-indicator/*
[131] *The State of nature report highlighting that 60% of farmland species are now in decline*
[132] *RSPB Farmland Bird Indicator: https://www.rspb.org.uk/our-work/conservation-and-sustainability/farming/near-you/farmland-bird-indicator/*

Spatial Configuration	No quantitative evidence	No target	Some improvements in landscape diversity are likely to have been made by AES and set aside schemes. However, the area of enclosed grassland showed a decline which will have reduced overall spatial configuration.
	B (unknown)		A (not discernible)

Table 38 Enclosed Grassland and Farmland – risk assessment (Mace et al. 2015)

	Cornwall Coastal Corridor		Rest of Cornwall UA		Cornwall UA		CC % Cornwall
	Ha	% of total	Ha	% of total	Ha	% of total	
Enclosed farmland	41377	64%	226649	76%	268026	74%	15%
Arable and horticulture	25056	39%	73564	25%	98620	27%	25%
Improved Grassland	16321	25%	153085	51%	169406	47%	10%

Table 39 Enclosed grassland and Farmland Extent (CEH 2017)

	Destroyed	Favourable	Partially Destroyed	Unfavourable Declining	Unfavourable – No change	Unfavourable recovering	
Enclosed Grassland	0	85.9	0	124.7	35.2	185.9	
Arable and horticulture	0	58.5				109.5	167.9
Improved Grassland	0	27.4		124.7	35.2	76.4	263.6
%		20%	0%	29%	8%	43%	431.5
Favourable/Unfavourable Recovering:							63%
Unfavourable, Declining, Partially Destroyed or destroyed							37%

Table 40. Enclosed Grassland and Farmland Condition Assessment (Natural England 2019)

Enclosed grassland			
	Quantity	Quality	Spatial Configuration
Food	☑	☑	
Fibre			
Energy			
Clean Water	☑	☑	
Clean Air			
Recreation			
Aesthetics			
Hazard Protection		☑	
Wildlife	☑	☑	☑
Equable climate		☑	

Table 41. Priority Ecosystem services for enclosed grassland and farmlands (NEA 2011; Mace et al 2015)

4.01.02 Woodlands

An estimated 9.6% of Cornwall is covered by woodlands, slightly below the percentage coverage for England [10%] and the UK [13%]. In comparison, 11% of the coastal corridor is classed as woodland, a notably higher percentage cover than the rest of Cornwall [9.2%] (see section 3.04.02). As shown in Table 43, the vast majority of this woodland is broadleaved [97%], reflecting wider trends in the rest of Cornwall where 83.5% of woodlands are broadleaved. Woodlands in the coastal corridor comprise an estimated 1,472 ha of ancient and semi-natural woodlands, 21% of the total amount in Cornwall. Furthermore, 4,529ha are classed as priority habitats - deciduous woodlands. ERCCIS (2009) records a gain of approximately 1000ha of broadleaved and coniferous woodlands in Cornwall between 1995 and 2005. Furthermore, the National Forest Inventory (NFI) indicates a significant percentage of 'ground prep' in the coastal corridor, some 66ha prepared for woodland planting in the coastal corridor, along with 352 ha of 'young trees', suggesting that the area of woodland in the coastal corridor is likely to expand in the future. The majority of the coniferous woodland in Cornwall is in the east, including east of Bodmin, along the A38, on Bodmin Moor. Within the coastal corridor, there is a clear clustering of woodland occurring around the south coast of Cornwall, with concentrations in the Fowey, Tamar, Fal and Helford estuaries.

By area, 92% of woodland SSSIs in the SW are classed as 'favourable' or 'unfavourable-recovering', just 8% are 'unfavourable', 'partially destroyed' or 'destroyed' (Natural England 2019). Woodland SSSI in the SW are close to meeting national targets to achieve ≥95% in favourable/recovering condition by 2020 (Biodiversity Strategy 2020, 2010), but considerable progress still needs to be made to meet the 25-year environment plan (2018) targets of ≥75% in favourable condition (Table 44). Nationally, there was no significant change in species richness in broadleaved or coniferous woodland between 1998 and 2007 (Countryside Survey 2007). The State of Nature report shows a major decline in butterflies (SoNE, 2008[133]), while nationally ~10% of vascular woodland plants are threatened.

Of all the natural capital assets present in the coastal corridor, woodlands have the potential to deliver the widest range of ecosystem goods and services. Mace et al. (2015) identify functional priority relationships between woodlands and eight ecosystem services, including fibre, clean water, clean air, recreation, aesthetics, hazard protection, wildlife and equable climate.

Woodlands			
Characteristic	Current Status	Target	Trend
Quantity	11% of the coastal corridor is wooded (CEH 2015)	12% woodland cover by 2060 (Defra Forestry and Woodlands Policy Statement, 2013) 12% woodland cover by 2060 (25-year Environment Plan)	The coastal corridor has a greater percentage cover of woodlands than the rest of Cornwall. ERCCIS records a gain of approximately 1000ha of broadleaved and coniferous woodlands between 1995 and 2005. Locally there has been an increased in the total extent of woodlands across the CAONB area, and a recorded shift from coniferous to mixed and broadleaved woodland (-13% coniferous woodlands) between 1995 and 2005. Since 1945, the area of woodland has doubled to cover 12% of the UK (UK NEA, 2011). Total area of the UK covered by woodland increased by 0.3% 2010 -2011 (ONS, 2012). There has also been an increase in UK woodland BAP habitats.
	A (just below target)		A (positive)
Quality	By area, 92% of woodland SSSI in the SW are in favourable/favourable recovering condition. *46% favourable* *46% unfavourable recovering* (NE 2019)	≥95% SSSI favourable/ recovering by 2020 (Biodiversity Strategy 2020) 75% of terrestrial and freshwater protected sites to <u>favourable condition</u> (25 Year Environment Plan 2018)	92% of woodland are in favourable/recovering condition in the SW, close to achieving national targets to achieve 95% in favourable/recovering condition by 2020. Nationally, there was no significant change in species richness in broadleaved or coniferous woodland between 1998 and 2007 (Countryside Survey 2007). The Woodland Bird Survey – mixed (1980s-2003/4) and major declines in butterflies (SoNE, 2008). Nationally ~10% vascular woodland plants threatened (SoNE, 2008).
	A (just below target)		B (negative)

[133] http://publications.naturalengland.org.uk/publication/31043

Spatial Configuration	Low connectivity across landscape (UK NEA, 2011). Our woodland resource is highly fragmented (Biodiversity Strategy 2020). For CUA mostly concentrated along the south coast estuaries.	No target	Little or no overall change in the degree of connectivity for broadleaved, mixed and yew woodland nationally between 1990 and 2007. Over the same period there has been an increase in the area of broad-leaved woodland, which would tend to increase connectivity (JNCC Biodiversity Indicators, 2013).
	B (unknown)		A (positive or not discernible)

Table 42. Woodlands – risk assessment (Mace et al. 2015)

	Coastal Corridor		Rest of Cornwall		Cornwall		CC % of total Cornwall
	Ha	% of total	Ha	% of total	Ha	% of total	
Woodland	7119.7	11%	27547.5	9.20%	34667.2	9.5%	10.4%
Broadleaved	6954.2	10.73%	23101.8	7.71%	30056.0	8.2%	8.2%
Coniferous	165.5	0.26%	4445.8	1.48%	4611.3	1.3%	2.1%

Table 43. Woodland extent in the coastal corridor (CEH 2017)

	Destroyed	Partially Destroyed	Unfavourable Declining	Unfavourable – No change	Unfavourable recovering	Favourable	
Woodland							
Broadleaved, mixed and yew woodlands - Lowlands	0	2.2	334.9	674.1	5724.1	5025.3	11760.6
Broadleaved, mixed and yew woodlands - Uplands	0		50.7	201.2	2165.1	2051.5	4468.4
Coniferous woodlands	0		40.1		52.6	912.8	1005.3
%	0%	0%	2%	5%	46%	46%	
Favourable/Unfavourable Recovering:							92%
Unfavourable, Declining, Partially Destroyed or destroyed							8%

Table 44. Woodland condition in the coastal corridor (Natural England 2019)

Woodlands			
	Quantity	Quality	Spatial Configuration
Food			
Fibre	☑	☑	
Energy			
Clean Water	☑		☑
Clean Air	☑		
Recreation	☑		☑
Aesthetics	☑	☑	☑
Hazard Protection	☑		☑
Wildlife	☑	☑	☑
Equable climate	☑		

Table 45. Priority Ecosystem services linked woodlands (NEA 2011; Mace et al 2015)

4.01.03 Coastal Margins

Coastal margins cover 5124 ha of the coastal corridor, approximately 8% of the total area of the corridor. The coastline boundary used for the coastal corridor is mean high water which means that a significant percentage of coastal margin habitats lie outside of the study area. However, the coastal corridor still holds 60.2% of all saltmarsh habitats in Cornwall, 74.8% of Supra littoral Rock and 87.9% of Supra Littoral Sediment. ERCCIS (2009) suggest that the extent of coastal and dune grassland habitats has remained relatively unchanged for the last decade, with a recorded loss of 2 ha of sand dunes between 1995 and 2005 (ERCCIS 2009), and a marginal change of -4.8 ha in the mapped physical extent of the coastal margins in the CAONB (Holzinger and Laughlin 2016). However, nationally, coastal margin habitats have suffered long term declines, an estimated 16% since 1952 (NEA, 2011). Furthermore, sea level rise projections leading to coastal squeeze could see continued losses of coastal margin habitats.

By area, 95.2% of coastal margin SSSI are classed as in favourable or recovering condition, just 4.8% are classed as unfavourable or declining. Notably, the quality or condition of these coastal margin habitats, and therefore their capacity and potential to deliver ecosystem services, is likely to be reduced due to coastal squeeze, arising from both sea level rise, coastal development, artificial sea defences reducing the mobility, and biological interest of these habitats. Indeed the quality of coastal margin habitats has declined since 1945 due to changes in soft sediment supply (SoNE, 2008). However, national studies have shown that the average number of water birds wintering-in, or migrating through, marine areas in the UK has doubled between the mid-1970s and mid-1990s.

Coastal margin habitats, such as sand dunes, salt marsh, shingle, sea cliffs, coastal lagoons, lie at the interface between the land and sea directly providing ecosystem services to both adjacent terrestrial and marine habitats. Nationally the value of ecosystem services provided by UK coastal margins is estimated at £48 million, equivalent to 3.46% of Gross National Income (NEA 2011[134]). For Cornwall, the ecosystem services of the greatest financial value are thought to be tourism and coastal defence. All coastal margin habitats contribute to coastal defence services provided by dissipating wave energy (e.g. saltmarsh attenuating wave energy) or regulating sediment supply (e.g. sand dunes acting as a barrier) (NEA 2011). It is estimated that nationally "*The soft coasts provide £3.1–£33.2 billion worth of capital savings in sea-defence costs"* (NEA 2011:3). Cultural ecosystem services, such as scenery, wildlife and leisure, are intrinsically linked to a national seaside tourism industry valued at £17 billion and a local industry valued are around £1.95 billion per year to the Cornish economy (NEA 2011; SWRC 2018). Due to the capacity for rapid soil development and high sediment accumulation rates, coastal margins could also act as crucial carbon sinks. Finally, coastal margin habitats provide important habitats for many rare species, particularly migrant birds, and some can act as crucial nursery grounds for many fish species and also support pollinators vital to arable and horticultural production in adjacent fields.

Coastal margins			
Characteristic	Current Status	Target	Trend
Quantity	5124 ha, equating to 8% of the coastal corridor. 37% of all coastal margin habitats in Cornwall	No target	ERCCIS (2009) records only a loss of 2 ha of sand dunes between 1995 and 2005 and a marginal change of -4.8 ha in the mapped physical extent of the coastal margins in the CAONB suggesting that the extent of coastal and dune grassland habitats has remained virtually unchanged. However, nationally, coastal margin habitats have suffered long terms declines, an estimated 16% since 1952 (UK NEA, 2011). Sea level rise projections leading to coastal squeeze could see continue losses of coastal margin habitats.
	B (unknown)		B (negative)
Quality	By area, 95% of SSSI coastal margins are in favourable or recovering condition. *82% favourable. 12.9% recovering*	≥95% SSSI favourable/ recovering by 2020 (Biodiversity Strategy 2020) 75% of terrestrial and freshwater protected sites to favourable condition (25 Year Environment Plan 2018)	Meets national targets under the 2020 Biodiversity strategy. Meets 25-year environment targets for 74% in favourable condition by 2020. Nationally, the average number of water birds wintering in, or migrating through, marine areas in the UK has doubled between the mid-1970s - mid-1990s. However, some species of diving duck and estuarine wader have recently declined (SoNE, 2008). The quality of coastal margin habitats has declined since 1945 due to changes in soft sediment supply (SoNE, 2008). Coastal squeeze and reduce mobility due to development is likely to reduce quality in the future.
	A (close to target)		B (not discernible)
Spatial Configuration	Unknown	No target	Unknown
	B (unknown)		B (unknown)

Table 46. Coastal margins - Natural Capital Risk Assessment (Mace et al. 2015)

[134] *NEA (2011) Coastal Margins* http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=dNI5e5W5I5Q%3D&tabid=82

	Coastal Corridor		Rest of Cornwall		Cornwall		CC % of total Cornwall
	Ha	% of total	Ha	% of total	Ha	% of total	
Coastal	5124.0	8%	8562.7	2.86%	13686.7	3.8%	37%
Saltmarsh	*657.1*	*1.01%*	*433.6*	*0.14%*	1090.7	0.3%	60.2%
Saltwater	*31.7*	*0.05%*	*2804.8*	*0.94%*	2836.5	0.8%	1.1%
Supra-littoral Rock	*1523.8*	*2.35%*	*513.1*	*0.17%*	2036.9	0.6%	74.8%
Supra-littoral Sediment	*2090.3*	*3.22%*	*286.6*	*0.10%*	2376.9	0.7%	87.9%
Littoral Rock	*483.3*	*0.75%*	*1515.6*	*0.51%*	1998.9	0.5%	24.2%
Littoral Sediment	*337.7*	*0.52%*	*3009.1*	*1.00%*	3346.8	0.9%	10.1%

Table 47. Coastal margin extent in the coastal corridor (CEH 2017)

	Destroyed	Partially Destroyed	Unfavourable Declining	Unfavourable – No change	Unfavourable recovering	Favourable	Total
	0.3	0	1145.9	615.5	4705.3	30102.2	36569.2
Supra-littoral Rock	0	0	43.3	32.1	1097.9	3705.1	4878.5
Supra-littoral Sediment	0.3	0	208.2	160.2	2633.6	464.6	3466.8
Inshore sublittoral sediment	0	0	141.2	167.3		287.6	596.1
Littoral Rock	0	0	37.2		68.6	877.9	983.7
Littoral Sediment	0	0	715.9	255.9	905.2	24767.1	26644.1
%			3.1%	1.7%	12.9%	82.3%	
Favourable/Unfavourable Recovering:							95.2%
Unfavourable, Declining, Partially Destroyed or destroyed:							4.8%

Table 48. Coastal Margin Condition in the SW (Natural England 2019)

Coastal Margins			
	Quantity	Quality	Spatial Configuration
Food			
Fibre			
Energy			
Clean Water			
Clean Air			
Recreation		☑	
Aesthetics		☑	☑
Hazard Protection	☑	☑	
Wildlife	☑	☑	
Equable climate	☑	☑	

Table 49. Functional relationships between coastal margins and ecosystem services (Mace et al 2015; NEA 2011)

4.01.04 Semi-Natural Grassland

Semi-Natural Grasslands (SNGs) account for only 1.2% of the area of natural capital assets in the coastal corridor, equating to only 5.2% of all SNGs in Cornwall. Notably, the coastal corridor is a significant reserve for neutral and calcareous SNGs in Cornwall, containing 81% of all calcareous grasslands and 53% of all neutral grasslands. Although there have only been minor recorded losses in the extent of remaining SNGs between 1995 and 2005 (ERCISS 2009), these minor losses need to be considered in relation to significant historic declines. Nationally, 47% of SNG were lost between 1960 and 2013 and this decline continues in some areas (UK NEA, 2011; Mace 2017; ONS, 2018[135]). Looking specifically at lowland SNGs, the NEA (2011) reports a 90% loss with the major driver being agricultural intensification.

As most SNGs are the product of traditional farming practices, conservation management is important to maintain condition. By area, 88.5% of Semi-Natural Grassland (SNG) SSSIs in the area are in 'favourable' or 'unfavourable but recovering' condition, whilst 11.5% are 'unfavourable', 'partially destroyed' or 'destroyed' (Natural England 2019). At 88.5% the condition of SSSI SNG is below but close to national targets aim to achieve ≥95% SSSI favourable/recovering condition by 2020 (Biodiversity Strategy 2020, 2010). However, considerable progress still needs to be made to meet the 25-year environment plan (2018) target of ≥75% of '*terrestrial and freshwater protected sites to favourable condition'.* Nationally there are further indications of widespread declines in the condition of SNGs, with significant declines in the plant species richness of SNG recorded between 1998-2007 (Countryside Survey 2007), and declines in butterflies and breeding and wintering birds associated with SNG (UK NEA, 2011).

Mace et al. (2015) identify functional priority relationships between SNG and key ecosystem services, including aesthetics, wildlife and equitable climate. SNGs are highly valued as supporting habitats for important and rare species. The NEA (2011) highlights that "*of the 1,150 species of conservation concern named in the UK Biodiversity Action Plan (UK BAP), lowland Semi-natural Grasslands are home to 206 UK BAP priority species, in comparison, upland SNGs are home to 41*" (NEA 2011:3[136]). SNG are also thought to have the potential to store more carbon than enclosed grassland and farmlands and produce less methane (NEA 2011). In terms of nectar production, they also provide crucial support for pollinators and pests with knock-on benefits for adjacent areas of arable and horticultural crops.

Semi-Natural Grassland			
Characteristic	Current Status	Target	Trend
Quantity	766 ha of the coastal corridor	No target	Minor loss in the extent of SNG recorded between 1995 and 2005. Loss of 150ha of neutral grassland, no loss of acid or calcareous grassland recorded (ERCISS 2009). CAONB (2015) study suggest a loss of -8.3 ha of SNG, a 0.1% loss between 1995 to 2005. These minor losses should be considered in relation to long term declines. Nationally between 1960 and 2013, 47% of SNGs were lost and this decline continues in some areas. The Countryside Survey 2007 highlights that there has been no change in the area of acid and calcareous grasslands in the UK. There was a significant increase in the area of neutral grassland (UK NEA, 2011; Mace 2017; ONS, 2018).
	B (Unknown)		B (negative)
Quality	By area, 88.5% of SW SSSI grassland (all types) are in favourable/ recovering condition. 37.5% in favourable condition. 51% recovering. (NE 2019)	≥95% SSSI favourable/ recovering by 2020 (Biodiversity Strategy 2020) 75% of terrestrial and freshwater protected sites to favourable condition (25 Year Environment Plan 2018)	88.5% of SNG SSSI in the SW are in favourable or recovering condition, -6.5% from national targets under the 2020 biodiversity strategy. The majority are recovering 51%, only 37.5% are in favourable condition. Nationally, neutral grassland is in stable condition. Calcareous grassland stable and under management to conserve, mixed improvements and declines in acid grassland (Countryside Survey 2007). Local data suggests that large areas of neutral and acid grassland are in declining condition. There has been a significant decline in plant species richness 1998-2007 (Countryside Survey 2007). Major declines in breeding and wintering birds associated with SNG, and butterflies (UK NEA, 2011).
	B (below the target)		B (negative)
Spatial Configuration	Unknown	No target	Unknown
	B (unknown)		B (unknown)

Table 50. Semi-Natural Grassland – risk assessment (Mace et al. 2015)

[135] ONS (2018) https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/uknaturalcapitaldevelopingseminaturalgrasslandecosystemaccounts
[136] http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=lfVaZJDoV8c%3D&tabid=82

	Coastal Corridor		Rest of Cornwall		Cornwall		CC % of total Cornwall
	Ha	% of total	Ha	% of total	Ha	% of total	
Semi-Natural Grassland	766.0	1.2%	14108.5	4.7%	14874.5	4.1%	5.2%
Calcareous	93.8	0.1%	21.4	0.01%	115.2	0.03%	81.4%
Acid	12.6	0.02%	10465.7	3.5%	10478.3	2.9%	0.1%
Neutral	47.3	0.07%	42.7	0.01%	90.0	0.0%	52.6%

Table 51. Semi-natural grassland extent (CEH 2017)

	Destroyed	Partially Destroyed	Unfavourable Declining	Unfavourable – No change	Unfavourable recovering	Favourable	Total
Semi-Natural Grasslands	1.3	205.9	3461.9	1905.5	24631.9	18126.5	48332.9
Acid grassland - Lowland			235.9	113.1	800.9	679.1	1829.1
Acid Grassland - Upland			8.1	970.6	4106.7	164.1	5249.5
Calcareous Grassland - Lowland	1.3	188.1	226.2	123.2	14138.8	13074.2	27751.7
Neutral Grassland – Lowland		17.8	2991.5	698.5	5574.8	4175.2	13457.9
Neutral Grassland - Uplands					10.8	33.9	44.7
%	0.0%	0.4%	7.2%	3.9%	51.0%	37.5%	
Favourable/Unfavourable Recovering:							88.5%
Unfavourable, Declining, Partially Destroyed or destroyed:							11.5%

Table 52. Semi-Natural Grassland Condition - SW SSSIs (Natural England 2019)

Semi-natural grasslands			
	Quantity	Quality	Spatial Configuration
Food			
Fibre			
Energy			
Clean Water			
Clean Air			
Recreation			
Aesthetics		☑	☑
Hazard Protection			
Wildlife	☑	☑	
Equable climate		☑	

Table 53. Semi-Natural grassland Priority functional relationship with ecosystem services (Mace et al 2015; NEA 2011)

4.01.05 Moors, heath and bog

Moors, heath and bog areas cover 3% [1846 ha] of the coastal corridor, accounting for 28% of Cornwall's moors, heath and bog habitat area. In the coastal corridor, this habitat type is dominated by heather and heather grassland areas; there is no bog habitat lying within the coastal corridor. Between 1995 and 2005, ERCCIS (2009) recorded a loss of 60 ha of inland rock and 17 ha of dwarf dry heath between 1995 and 2005.

By area, 95% of moor, heath and bog SSSIs in the SW are thought to be in 'favourable' or 'unfavourable but recovering' condition, with only 5% in 'unfavourable', 'partially destroyed' or 'destroyed', close to meeting national targets to achieve ≥95% SSSI favourable/ recovering by 2020 (Biodiversity Strategy 2020, 2010; Natural England 2019). However, just 19% of moors, heath and bog in the SW are classed as in favourable condition, and therefore considerable progress still needs to be made to meet the 25-year environment plan (2018) targets of ≥75% of '*protected sites in favourable condition'.*

Mace et al. (2015) identify functional priority relationships between moors and heathland and five priority ecosystem services: clean water, aesthetics, hazard protection, wildlife and equitable climate.

Moors, heath and bog			
Characteristic	Current Status	Target	Trend
Quantity	1847 ha, 3%, of the coastal corridor consists of bogs, heath and inland rocks.	The SW nature map targets a 40% increase in upland and lowland heath habitats.	Between 1995 and 2005, ERCISS (2009) records losses of 60 ha of inland rock and 17 ha of dwarf dry heath. The physical extent of heathland has slightly declined in the CAONB between 1995 and 2005 (-3.4 ha). Nationally, peatland bog areas decreased significantly over the last 60yrs, area of active peat bog declining by <1% per annum, 1990 to 1998 (UK NEA, 2011).
	B (Unknown)		B (negative)
Quality	By area, 94.8% of Moors, heath or bog SSSI are in favourable or recovering condition *19% Favourable* *75% Recovering*	≥95% SSSI favourable/ recovering by 2020 (Biodiversity Strategy 2020) 75% of terrestrial and freshwater protected sites to <u>favourable condition</u> (25 Year Environment Plan 2018)	Very close to achieving the 2020 biodiversity strategy for 95% of SSSI in favourable or recovering condition. However, only 19% are in favourable condition a significant departure from the 75% target for the 25-year environment plan. Nationally lowland heath birds recovering, upland wetland birds declining (SoNE, 2008) Vegetation richness stable 1998-2007 (Countryside Survey 2007)
	A (At or close to target)		A (positive or not discernible)
Spatial Configuration	Unknown	No target	Unknown
	B (Unknown)		B (Unknown)

Table 54. Moors, heather and bog assessment (Mace et al. 2015)

	Coastal Corridor		Rest of Cornwall		Cornwall		CC % of total Cornwall
	Ha	% of total	Ha	% of total	Ha	% of total	
Moors, heather and bog	1846.9	3%	4727.6	1.58%	6574.5	1.8%	28%
Bog	*0*	*0*	*376.6*	*0.13%*	376.6	0.1%	
Heather	*1819.7*	*2.81%*	*4305.1*	*1.44%*	6124.8	1.7%	*29.7%*
Heather grassland	*612.3*	*0.94%*	*3578.8*	*1.19%*	4191.1	1.2%	*14.6%*
Inland Rock	*6.0*	*0.01%*	*2636.7*	*0.88%*	*2642.7*	*0.7%*	*0.2%*

Table 55. Moors, heather and bog habitat extent (CEH 2017)

	Destroyed	Partially Destroyed	Unfavourable Declining	Unfavourable – No change	Unfavourable recovering	Favourable	Total
	1.3825	16.5	1201.9	1744.4	43001.4	11061.6	57027.3
BOGS - Lowland		15.9	13.9	53.0	296.4	121.9	501.3
BOGS - Upland			272.7		15295.5	1042.9	16611.3
DWARF SHRUB HEATH - Lowland	1.3825	0.6	565.9	1105.5	7349.8	6225.6	15248.8
DWARF SHRUB HEATH - Upland			336.1	585.9	19957.4	3671.1	24550.4
BRACKEN			13.3		102.3		115.57
	0%	0%	2%	3%	75%	19%	
Favourable/Unfavourable Recovering:							94.8%
Unfavourable, Declining, Partially Destroyed or destroyed:							5%

Table 56. Moors, heather and bog condition assessment SW SSSIs (Natural England 2019)

Moors and heath			
	Quantity	Quality	Spatial Configuration
Food			
Fibre			
Energy			
Clean Water		☑	
Clean Air			
Recreation			
Aesthetics		☑	☑
Hazard Protection	☑	☑	
Wildlife	☑	☑	
Equable climate		☑	

Table 57. Moors, heather and bog priority ecosystem services (Mace et al. 2015; NEA 2011)

4.01.06 Fen, Marsh and Swamp

There are only an estimated 27 ha of fen, marsh and swamp habitat in the coastal corridor, equating to only 0.04% of the total area of the corridor, and 0.1% of this habitat type in Cornwall. ERCCIS (2009) records a loss of 30ha of fen, marsh and swamp in Cornwall between 1995 and 2005. Nationally, this habitat is widely scattered across the lowlands but restricted in distribution. The condition of fen, marsh and bog habitat is thought to be relatively poor with a 20% increase in condition, by area, needed to reach 2020 targets, and 36% increase needed to reach 25-year environment plan targets.

Fen, Marsh or Swamp			
Characteristic	Current Status	Target	Trend
Quantity	25 ha in the coastal corridor, 0.2% of the total extent of this habitat across Cornwall.	No target	ERCCIS records a loss of 30ha of fen, marsh and swamp in Cornwall between 1995 and 2005.
	B (unknown)		B (negative)
Quality	By area, 75% are in favourable or recovering condition. *39% favourable.* *36% recovering.*	≥95% SSSI favourable/ recovering by 2020 (Biodiversity Strategy 2020) 75% of terrestrial and freshwater protected sites to favourable condition (25 Year Environment Plan 2018)	By area, a 20% improvement in condition is needed to reach 2020 targets, 36% increase needed to reach 25-year environment plan targets. Bird data is mixed - wet meadows declined, reed beds increased, slow/standing water increased, wetland birds declined with increasing severity in recent years (UK NEA, 2011). Impacted by the decline of traditional management practices and drainage.
	B (below target)		B (negative)
Spatial Configuration	Unknown	No known target	Nationally, widely scattered across the lowlands but restricted in distribution.
	B (unknown)		B (unknown)

Table 58. Fen, Marsh and Swamp – risk assessment (Mace et al. 2015)

	Coastal Corridor		Rest of Cornwall		Cornwall		CC % of total Cornwall
	Ha	% of total	Ha	% of total	Ha	% of total	
Fen, Marsh or Swamp	27.2	0.04%	45.8	0.02%	73.0	0.02%	0.1%

Table 59. Fen, Marsh and Swamp extent (CEH 2017)

	Destroyed	Partially Destroyed	Unfavourable Declining	Unfavourable – No change	Unfavourable recovering	Favourable	Total
Fen, marsh or swamp	0	12.1	1000.4	72.4	1611.5	1721.0	4417.4
Lowland		12.1	1000.4	72.4	1178.8	1543.9	3807.6
Upland					432.7	177.2	609.89
%		0	23%	2%	36%	39%	
Favourable/Unfavourable Recovering:							75%
Unfavourable, Declining, Partially Destroyed or destroyed:							25%

Table 60. Fen, Marsh and Swamp Condition – SW SSSI condition (Natural England 2019)

4.01.07 Freshwater

Freshwater habitats cover 0.12% of the coastal corridor, accounting for 5.2% of the total extent of freshwater habitats across Cornwall. BAP priority rivers[137] include all natural and near-natural running waters in the UK (i.e. with features and processes that resemble those in natural systems), and these range from upland streams to meandering lowland rivers. Notably, the coastal corridor contains 48% of all priority river, by length, in Cornwall. Twelve BAP priority rivers run through the coastal corridor, around 16.6km, 48% of the total length of priority rivers across Cornwall. Rivers are relatively evenly distributed across Cornwall, their management is divided into three river basin district catchments: West Cornwall and Fal, North Cornwall, Seaton, Looe and Fowey and the Tamar (Environment Agency, 2009). There are four major rivers in the area: the Tamar, Fowey, the Fal and the Hayle. The majority of large freshwater bodies lie outside of the coastal corridor on Bodmin Moor, with the exception of Argal and College Reservoirs near Penryn, The Loe near Porthleven and Drift Reservoir near Penzance. In terms of the coastal corridor, the majority of priority habitats include the Fowey, West Looe River, Trebank Water, River Lerryn, River Valency, Tregeseal Stream, River Gannel, River Jordan, Penpoll Creek, St Gluvian Stream and Tresillian River. 68% of SSSI are in favourable or recovering condition. Between 2009-2013 no river in Cornwall was classed as having high water quality (Cornwall Council 2015[138]). Pollution from wastewater was affecting 33% of water bodies in the SW, with physical modification affecting 22%.

Mace et al. (2015) identify functional priority relationships between freshwater habitats and the provisioning ecosystem services including clean water, recreation, aesthetics, hazard protection, wildlife and equable climate.

Freshwater			
Characteristic	Current Status	Target	Trend
Quantity	80 ha of freshwater habitats lie within the coastal corridor (LCM 2015), just 0.12% of total area of the coastal corridor. Including 286km of rivers and water bodies.	No national target ~ 1.1% (UK wide) of land for wetlands (lowland) is needed to deliver sustainable populations of all birds (RSPB pers. Comm. Jo Gilbert 2007) (Hume, 2008 – Wetland Vision Technical Document).	ERCCIS reports no change in the area of rivers and streams across Cornwall between 1995 and 2005 and an increase of standing open water and canal of 110ha. Notably a large percentage of this increase in freshwater was due to the creation of a large lake on Bodmin Moor which is not of relevance to the coastal corridor, however, CAONB also reports the creation of several new pond sites across the AONB. Nationally, ~90% of the national resource of wetlands has been lost since Roman times.
	B (significantly below target)		A (positive or not discernible)
Quality	27% of England's freshwater bodies are currently classified as being of 'good status' or 'good ecological potential' or better (Environment Agency) By area, 68% in favourable or recovering condition *55% favourable* *13% recovering*	All inland and coastal waters within defined river basin districts must reach at least good status by 2015 (WFD) ≥95% SSSI favourable/ recovering by 2020 (Biodiversity Strategy 2020)	68% of SSSI are in favourable or recovering condition. Between 2009-2013 no river in Cornwall was classed as having high water quality. Pollution from waste water was affecting 33% of water bodies in the SW, with physical modification affecting 22%. Nationally, between 1996-2007 plant species richness in ponds decreased by 20% and proportion of poor or very poor quality ponds increased by 17% (UK NEA, 2011). National bird data is mixed - wet meadows declined, reed beds increased, slow/standing water increased, wetland birds declined with increasing severity in recent years (UK NEA, 2011)
	B (Significantly below target)		B (decline)
Spatial Configuration	Unknown	No target	Unknown
	B (unknown)		B (Unknown)

Table 61 Freshwater – risk assessment (Mace et al. 2015)

	Coastal Corridor		Rest of Cornwall		Cornwall		CC % Cornwall
	Ha/km	% of total	Ha	% of total	Ha	% of total	

[137] BAP Priority Rivers include (1) Rivers of high hydromorphological status under the EC Water Framework Directive (WFD); (2) Headwaters; (3) Occurrence of the EC Habitats Directive Annex I habitat H3260 'Water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation'. This includes, but is not confined to, all river Special Areas of Conservation (SACs) designated for the feature. (4) Chalk rivers, as described in the pre-existing BAP definition (5) Active shingle rivers (6) Areas or Sites of Special Scientific Interest (ASSIs or SSSIs) designated for river species, riverine features or fluvial geomorphology. This also includes Geological Conservation Review (GCR) and Earth Science Conservation Review (ESCR) sites of importance for fluvial geomorphology. (6) The presence of priority or indicator species, including: Annex II Habitats Directive species; BAP priority species; and invertebrate species which are strongly indicative of river shingle.

[138] Environmental Growth Strategy (2015)

Freshwater Land Cover (ha) *(LCM 2015)*	80.8	0.12%	1173.3	0.39%	1254.1	0.3%	
Rivers/ water bodies (km)	286		2046		2332		CC % Cornwall
Canal	*1.7*	1%	0.4	0.02%	2.1	0.09%	81%
Inland Rivers	*269.3*	94%	1805.4	88.24%	2074.7	88.97%	13%
Lake	*6.7*	2%	30.1	1.47%	36.8	1.58%	18%
Coastal Rivers	*8.4*	3%	211	10.31%	219.4	9.41%	4%

Table 62. Freshwater habitat extent (CEH 2017)

	Destroyed	Partially Destroyed	Unfavourable Declining	Unfavourable – No change	Unfavourable recovering	Favourable	Total
Freshwater	0	0	307.9	579.9	343.7	1477.8	2709
Rivers and Streams	0	0	53.2	420.3	98.8	137.0	
Standing Open Water	0	0	254.8	159.6	244.8	1340.9	
%	0%	0%	11%	21%	13%	55%	
Favourable/Unfavourable Recovering:							68%
Unfavourable, Declining, Partially Destroyed or destroyed:							32%

Table 63. Freshwater habitat condition assessment SSSI in the SW (Natural England 2019)

	Freshwater		
	Quantity	Quality	Spatial Configuration
Food			
Fibre			
Energy			
Clean Water	☑	☑	
Clean Air			
Recreation		☑	
Aesthetics		☑	
Hazard Protection		☑	☑
Wildlife	☑	☑	☑
Equable climate	☑	☑	

Table 64. Freshwater habitat priority ecosystem services (Mace et al 2015; NEA 2011)

4.02 PHYSICAL FLOW ACCOUNTS

The asset register provides a catalogue of the natural capital assets present within the coastal corridor and an initial outline of the ecosystem services that these assets are thought to be functionally important for. The register shows that the corridor is dominated by enclosed grasslands, focused on provisioning services (food), with smaller but still significant amounts of woodlands and coastal margin habitats delivering multiple services including carbon sequestration, hazard regulation, aesthetics, recreation, water quantity and quality. This section aims to provide a more detailed impression of the potential of habitats in the coastal corridor to deliver ecosystem goods and services.

A range of methodologies have been used to attempt to quantify flows of ecosystem services, and where it has not been possible to quantify these an attempt has been made to instead highlight whether the corridor is important for the delivery of a certain ecosystem good or service. Where feasible, comparisons have been made to the rest of Cornwall. It has not been possible to include all ecosystem goods and services in the physical flow accounts, but only those with sufficient available data and established methodologies to enable measurement within the project timescale. The flows of ecosystem goods and services reported here should be treated as potential flows or capacity to deliver, rather than reporting specific flows of goods and services that the corridor currently delivers, as this would in many cases require detailed analysis of beneficiaries. The methodology used for each good or service is set out in each individual section.

4.02.01 Regulating Ecosystem Services

Climate regulation – Carbon Storage and Sequestration

- *Soils (150cm depth) and vegetation in the coastal corridor are estimated to store approximately 9 million tonnes of carbon, equating to around 14.3% of Cornwall's total stored carbon.*
    - *Soils (estimated down to 150cm in depth) store an estimated 15 times the amount of carbon compared with above-ground vegetation.*
    - *The coastal corridor stores 20% of Cornwall's total above-ground carbon storage. The high level of above-ground carbon storage potential in the coastal corridor is a result of the large woodland area.*
- *A rudimentary assessment of the value of stored carbon, based on non-traded value, suggests that the stock value of carbon stored in the coastal corridor is around £603 million (not a flow value of ecosystem services).*
- *Based on the habitat types with available carbon sequestration data, the coastal corridor is estimated to have the potential capacity to sequester around 55 thousand tonnes of CO_{2e} per yr. This equates to around 17% of the total amount sequestered in Cornwall.*
- *A rudimentary assessment of the value of sequestered carbon, based on non-traded value, by habitats in the coastal corridor, has an estimated value of £3 million per year (2019 prices). Notably, this figure does not take into account future rises in the price of carbon.*

Vegetation and soils in the coastal corridor can help to regulate climate by sequestering and storing carbon. The potential capacity of the coastal corridor to help regulate climate change has been estimated in terms of carbon storage capacity and carbon sequestration potential of the broad habitat types present in the corridor, no attempt has been made to measure carbon emission. Carbon storage capacity refers to the approximate amount of carbon that can be sequestered or stored naturally in soil and vegetation. Natural capital assets that store carbon include soils and above-ground vegetation, which take in carbon dioxide through photosynthesis and act as a carbon sink. Different habitat types have differing capacity to store carbon, while the restoration of some degraded habitats can lead to increased capacity for carbon storage. Carbon sequestration refers to the additional carbon drawn down by certain vegetation types annually.

Estimates of the amount of carbon stored and sequestered in the coastal corridor are made based on existing literature on the average amount (tonnes) of carbon stored in different broad habitat types and for the top 150cm of soil using the LandIS, NATMAPcarbon, Soil Organic Carbon map (Cranfield University 2019[139]). Carbon storage and sequestration estimates are limited as they do not attempt to take into account the habitat condition, age or management regime of each habitat, which are all likely to cause variation in the capacity of different habitats to store carbon, particularly woodlands. Furthermore, these estimates do not

[139] *LandIS (2019) NATMAP CARBON: Soil Organic Carbon Map, Available At: http://www.landis.org.uk/data/nmcarbon.cfm*

capture carbon stored in any deeper soils below 150cm. Additional work could be undertaken to estimate the carbon emission from the coastal corridor, linked to livestock present in the corridor and arable farming.

Carbon Storage: Above and below ground

Above-ground

Estimates of mean carbon stocks, in tonnes of carbon per ha, stored in above ground vegetation have been developed through a number of research projects (e.g. Read et al 2009[140]; Alonso et al. 2012[141]). The total amount of carbon storage was calculated by multiplying average tonnes per ha by the area of each habitat type present within the coastal corridor. Mean carbon tonnes stored per ha per habitat are shown in Table 74.

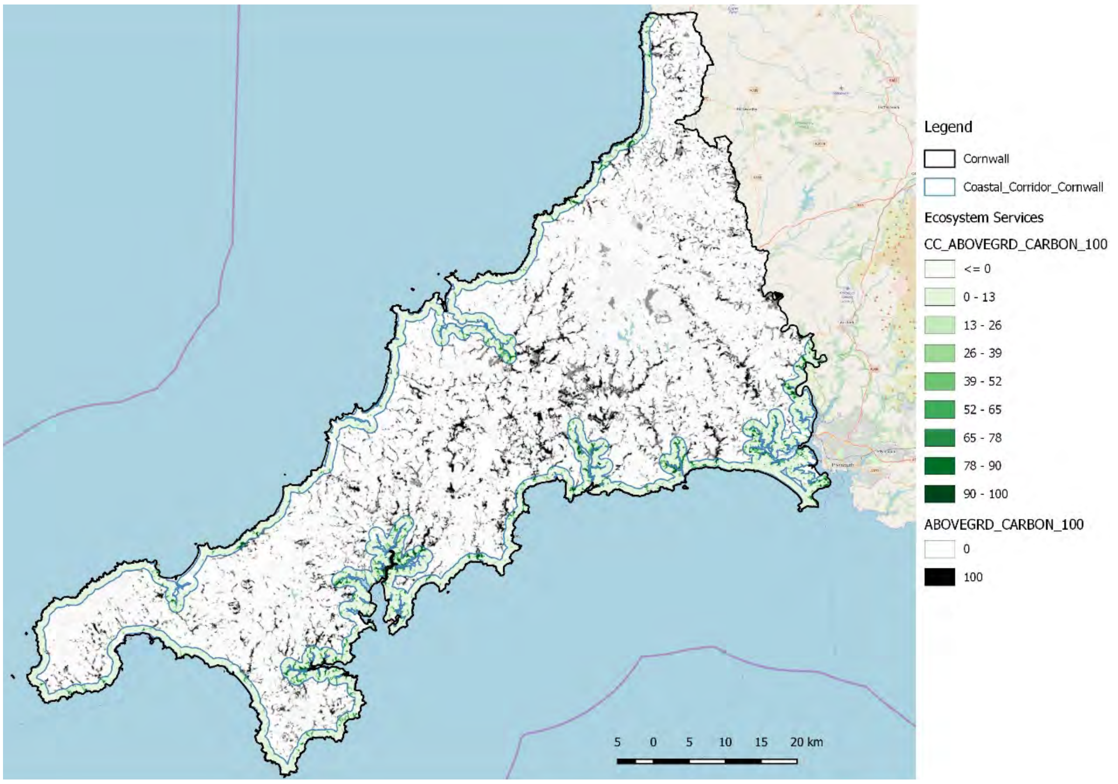
Based on mean carbon stored (ha/annum) per broad habitat type, it is estimated that the coastal corridor holds around 547,197 tonnes in above-ground carbon (Table 74). Carbon stored in the coastal corridor equates to approximately 20% of the total above-ground carbon stored in Cornwall. In using these figures, it must be acknowledged that these calculations are limited. As shown in Table 74, data on carbon stored per ha is not available for every habitat type. Furthermore, existing research literature highlights that carbon density for woodlands should be based on species and age-specific estimates which have not been taken into account here. Map 7 show levels of above ground carbon in vegetation across the coastal corridor (National Soil Maps 2019) which closely follows the geographical distribution of woodlands across the coastal corridor, with high densities mainly concentrated around wooded valleys and estuaries in the southern section of the coastal corridor.

Broad Habitat Group	Net Carbon Storage (t/ha)	Source	Coastal Corridor Area (Ha)	Coastal Corridor Stock of Carbon (Tonnes)	Cornwall Area (ha)	Cornwall Stock of Carbon (tonnes)	CC as % of Cornwall carbon Stock
Broadleaved Woodland	70	Alonso et al (2012)	6954.2	486794	30056	2103920	23%
Coniferous Woodland	70	Alonso et al (2012)	165.5	11585	4611.3	322791	4%
Arable and Horticultural	1	Henrys et al (2007)	25055.6	25055.6	98619.9	98619.9	25%
Improved Grassland	1	Henrys et al (2007)	16321.2	16321.2	169406.1	169406.1	10%
Neutral grassland	1	Henrys et al (2007); Alonso et al (2012)	47.3	47.3	90	90	53%
Calcareous Grassland	1	Henrys et al (2007)	93.8	93.8	115.2	115.2	81%
Acid Grassland	1	Henrys et al (2007); Alonso et al (2012)	12.6	12.6	10478.3	10478.3	0%
Dwarf Shrub Heath	2	Henrys et al (2007); Alonso et al (2012); Ostle et al (2009)	2432	4864	10315.9	20631.8	24%
Fen, Marsh and Swamp	2	Henrys et al (2007)	27.2	54.4	73	146	37%
Bog	2	Henrys et al (2007); Alonso et al (2012)	0		376.6	753.2	0%
Sand dunes	0.65	Cannell and others (1999)	2090.3	1358.7	2376.9	1544.9	88%
Saltmarsh	1.415	Cannell and others (1999)	657.1	929.8	1090.7	1543.3	60%
Other coastal habitats	Unknown		2376.5		10219.1		
Other habitats (inland rock)	Unknown		6		2642.7		
Urban or suburban	Unknown		8519.9		22644.1		
Freshwater	1		80.8	80.8	1254.1	1254.1	6%
TOTAL				547,197		2,731,294	20%

Table 74. Carbon storage by broad habitat group in the coastal corridor (multiple sources as stated)

[140] *Read et al.(eds) (2009) Combating climate change – a role for UK forests. An assessment of the potential of the UK"s trees and woodlands to mitigate and adapt to climate change. The Stationery Office, Edinburgh.*

[141] *Alonso et al. (2012) Carbon storage by habitat: Review of the evidence of the impact of management decisions and condition of carbon stores and sources. Natural England Research Reports.Natural England. Sheffield.*



Map 7. Above-ground carbon storage (National Soil Maps 2019; Mosedale In press)

Below-ground

Below-ground carbon storage has been estimated using the LandIS National Soil Map (Cranfield University 2019[142]) which provides estimates of the average stock of organic carbon in soils at three depths, 0-30cm, 30-100cm and 100-150cm, per unit area. The National Soil Map NATMAP carbon dataset has been used to estimate the expected carbon stock in soils across Cornwall to 150cm in depth and takes into account the variation of organic carbon (OC) in relation to different land uses. Based on mean carbon stored (ha/annum) for all three soil depths, it is estimated that the coastal corridor holds around 8,464,081 tonnes of below-ground carbon (Cranfield University 2019).

	Coastal Corridor (tCO2e)	Cornwall (tCO2e)
0 to 30cm	5,585,174 (66%)	36,546,210 (61%)
30 to 100cm	2,564,813 (30%)	19,395,666 (32%)
100 to 150cm	314,031 (4%)	3,984,093 (7%)
Total soil organic carbon stock (tonnes)	8,464,018	59,925,968 (14%)

Table 75. Stored soil carbon, estimated to 150cm in depth (Source: NSRI soils data

Total Stored Carbon: Above- and Below-ground Carbon Stocks

The coastal corridor has the potential to store an estimated 9 million tonnes of carbon, equating to around 14.3% of Cornwall's total stored carbon. A rudimentary estimate of the stock value of carbon stored in the coastal corridor, following BEIS guidance on valuing non-traded carbon at £67/tCO2e, is £603m (not a flow value of ecosystem services). This approach to valuing stored carbon is acknowledged to be limited. In terms of distribution, the lowest carbon stores were found to be in enclosed grassland habitats, and carbon storage was (as expected) much higher in soils than above-ground vegetation. Notably, there are particularly high levels of potential carbon storage around West Cornwall and Bodmin Moor, west of Falmouth and to the north of St Austell (except for China Clay district). The highest areas of potential carbon storage in above ground vegetation are found close to Bodmin Moor and East Cornwall, along the River Tamar, reflecting the high-density woodlands in these areas.

[142] *LandIS (2019) NATMAP CARBON: Soil Organic Carbon Map, Available At: http://www.landis.org.uk/data/nmcarbon.cfm*

	Coastal Corridor (tCO2e)	Cornwall (tCO2e)
Above-ground	547,197	2,731,294
Below-ground (<150cm)	8,464,018	59,925,968
Total Carbon Stored	9,011,215 (14.3%)	62,657,262

Table 76. Total stored carbon (NSRI NATMAP Carbon 2019)

Carbon Sequestration

In addition to the stock of stored carbon in the natural environment, vegetation also sequesters additional carbon each year as it grows. Carbon sequestration is the annual flow or intake of carbon by vegetation each year. Different vegetation types sequester carbon at different rates, active peat bogs and woodlands are known to be particularly effective. Table 77 below outlines the available carbon sequestration rates for different broad habitat types based on available academic data (see Christie et al. 2010; Beaumont et al. 2014; Broadmeadow and Matthews 2003; White et al. 2015; Alonso et al. 2012; Carnell et al. 1999; Jones et al. 2008). Carbon is also emitted at different levels each year depending on the mix of livestock and arable farming in place, as this mix of farming cannot be estimated for the coastal corridor carbon emissions have not been calculated, only capacity for sequestration.

The coastal corridor is estimated to have the capacity to sequester around 55 thousand tonnes of CO_{2e} per yr, 17% of the total amount sequestered in Cornwall (in using this figure it must be acknowledged that emissions by land cover have not been included). A crude estimate of the value of these carbon sequestration services, using BEIS guidance on valuing non-traded carbon at £67/tCO2e the value per year, is approximately £3 million per year. Improved estimates of the value of sequestered carbon could be made using estimates of carbon price fluctuations over the next 50 years.

Broad Habitat	tCO2 per year/ha	Range	Source	Coastal Corridor		Cornwall		% CC of total
				Area	tonnes CO2e per yr	Area	tonnes CO2e per yr	
Broadleaved Woodland	4.970		Christie et al. (2010)[143] assumes values for beech trees	6954.2	34562.3	30056	149378.3	23%
Coniferous Woodland	12.66		Assumes values for sitka spruce	165.5	2095.2	4611.3	58379.1	4%
Arable and horticulture	0.107		Christie et al (2010) Assumes values for cropland	25055.6	2680.9	98619.9	10552.3	25%
Improved Grassland	0.397		Christie et al. (2010)	16321.2	6479.5	169406.1	67254.2	10%
SNGL	0.397		Christie et al. (2010)	153.7	61	10683.5	4241.3	1%
Heather (lowland and upland heath)	0.7	Assuming average values for bogs and heath	Christie et al. (2010)	1819.7	1273.8	6124.8	4287.4	30%
Heather grassland	0.7	Assuming average values for bogs and heath	Christie et al. (2010)	612.3	428.61	4191.1	2933.77	15%
Bog (lowland raised bog)	0.675	(0.45-0.9)	Christie et al. (2010)	0	0	376.6	254.205	0%
Blanket bog/ Bog uplands	0.7		Broadmeadow and Matthews (2003)[144] Christie et al. (2010)		0		0	
Fen, marsh and swamp	0.7	Assuming average values for bogs and heath	Christie et al. (2010)	27.2	19.04	73	51.1	37%
Montane habitats	0.7		Christie et al. (2010) Assuming average values for bogs and heath		0		0	
Saltmarsh	5.188	2.35 to 8.04	Beaumont et al. (2014)[145]; Carnell et al. (1999)	657.1	3409.0348	1090.7	5658.5516	60%
Supralittoral sediment: Sand Dune	2.182		Beaumont et al. (2014); Jones et al. (2008)[146]	2090.3	4561.0346	2376.9	5186.3958	88%
Intertidal mud	0.59		Andrews et al. (2006)[147]	31.7	18.703	2836.5	1673.535	1%
Subtidal coarse and sandy sediments	0.37		Painting et al. (2010)[148]	337.7	124.949	3346.8	1238.316	10%
Supra littoral rock	0	Assumes no veg	White et al. (2015)[149]	n/a	n/a	n/a	n/a	

---

[143] *Christie et al. (2010) Economic Valuation of the Benefits of Ecosystem Services delivered by the UK Biodiversity Action Plan, Defra Project: NE0112, Final report. Available at: http://users.aber.ac.uk/mec/Publications/Reports/Value%20UK%20BAP%20FINAL%20published%20report%20v2.pdf*
[144] *Broadmeadow and Matthews (2003) Forest, carbon and climate change: the UK contribution. Forestry Commission Information Note 48.*
[145] *Beaumont et al. (2014) The value of carbon sequestration and storage in coastal habitats. Estuarine, Coastal and Shelf Science, 137. 32-40. https://doi.org/10.1016/j.ecss.2013.11.022*
[146] *Jones et al. (2008) Factors controlling soil development in sand dunes: evidence from a coastal dune soil chronosequence. Plant Soil, 307: 219-234.*
[147] *Andrews et al. (2006) Biogeochemical value of managed realignment, Humber estuary, UK. Science of The Total Environment, 371: 19-30*
[148] *Painting et al. (2010) Defra report MEC3205. Results of fieldwork to quantify key process affecting the flow of C, N, O and Si at key sites in the North Sea. 65pp.*
[149] *White et al. (2015) Ecosystem accounts for protected areas in England and Scotland: technical appendix, report to Defra, Available at: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19271*

Inland Rock	0	Assumes no veg	White et al. (2015)	n/a	n/a	n/a	n/a	
Freshwater	No data		White et al. (2015)	n/a	n/a	n/a	n/a	
TOTAL					55,714.2		311,088.5	17%

Table 77. Carbon sequestration in the coastal corridor (multiple sources)

Soil Erosion Mitigation and Land Loss

- *The coastal corridor experiences an average estimated loss of around 180,182 tonnes of soil per year through water erosion, and an estimated 27,870 tonnes of soil per year through wind erosion. Notably, predicted mean tonnes of soil eroded by wind in the coastal corridor is almost four times higher than for the rest of Cornwall.*
- *There is considerable potential to enhance natural capital assets and change land management practice to reduce wind and water erosion across the coastal corridor, with particular needs to mitigate the effect of water erosion around Falmouth, Tamar estuary, Looe, St Martin, Saltash, Fowey, Megavisey and Gorran Haven, Truro and in the north around Bude, Camel Estuary, and Wadebridge; and wind erosion around Newquay airport, Padstow, Crackington Haven to Bude areas.*
- *In terms of sea level rise predictions there are suggestions that over the long term (100 years) the coastal corridor will lose an area of some 258 ha along the coastline, in the medium term (the next 50 years) a loss of 144 ha, and in the short term (next 20 years) a loss of 74 ha.*

Soils perform a variety of key ecosystem services such as '*nutrient cycling, regulating water and nutrient flows, filtering toxic compounds, providing a medium for plant roots and supporting the growth of a variety of animals and soil micro-organisms by providing a diverse physical, chemical and biological habitat*'. The erosion of soils has major implications not only for farm productivity and crop production but also by reduced water quality by entering freshwater systems and causing eutrophication with implications for drinking water treatment. Eroded soils often need to be removed from roads, reservoirs and estuaries, while the loss of soils has also reduced below-ground carbon stocks (as set out in the previous section). Soil erosion has a variety of causes, including animal and crop production on inappropriate land, overstocking, bad timing of agricultural practices, degradation of riverbanks by stock, and lack of ground cover in winter months (wind, water, crop production etc).

High levels of soil erosion is a particular issue for Cornwall. In 1991 the Tamar catchment had an estimated gross erosion rate of 5.3 tonnes/ha/year (Quine and Walling 1991[150]), more than double the mean soil loss rate for the European Union (2.46 t/ha/yr). Since the 1990s, a number of projects have worked to try to reduce soil erosion to improve water quality, including the Cornwall's rivers project working in the Fal and Tresillian area 2002-2006 and the South Cornwall River Improvement Project (SCRIP) (2012-2015). Climatic warming could exacerbate soil erosion problems in Cornwall, as drier soils are predicted to lead to carbon loss and wetter soils to be more vulnerable to structural damage. A soil vulnerability map produced by the EA (2012) suggested that the majority of soil types in Cornwall are at medium to high risk.

Enhancing natural capital assets and changes to land management practice have considerable potential to mitigate for soil erosion by acting as a physical barrier (vegetation) to erosion and absorbing some of the energy of wind or water causing soil erosion. The potential of the coastal corridor to mitigate for soil loss was therefore estimated based on understanding of the current level of potential erosion by water and wind. Assessment of soil erosion by water using the European Soil Data Centre data (Panagos et al. 2015[151]) suggests that the mean amount of erosion by water is slightly lower in the coastal corridor compared to the rest of Cornwall, however the coastal corridor is still losing some 180,182 tonnes of soil per year, 17.6% of the total estimated amount of soil eroded across Cornwall. There are particularly high levels of erosion by water along the south coast, around Falmouth, Tamar estuary, Looe, St Martin, Saltash, Fowey, Megavisey and Gorran Haven, Truro and in the north around Bude, Camel Estuary, and Wadebridge. Enhancing natural capital assets and changing land management practice in this area could help significantly to reduce soil erosion by water. Using European Soil Data Centre data on the potential for soil erosion by wind (Borrelli et al 2017[152]), indicates that mean soil erosion by wind (t/ha/yr) is predicted to be almost four times higher in the coastal corridor than the whole of Cornwall. Notably, the highest levels of predicted erosion of soil erosion by wind are around Newquay airport, Padstow, Crackington Haven to Bude areas. Estimates of potential soil loss by wind for the whole of the coastal corridor, using mean t/ha/yr, suggest that there is a potential loss of around 27,870 tonnes of soil per year, 45% of the total estimated amount of erosion by wind for the whole of Cornwall.

---

[150] *Quine and Walling (1991) Rates of soil erosion on arable fields in Britain: quantitative data from caesium-137 measurements, Soil Use and Management,7 (4): 169-176, https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1475-2743.1991.tb00870.x*

[151] *Panagos et al. (2015) The new assessment of soil loss by water erosion in Europe. Environmental Science & Policy. 54: 438-447. DOI: 10.1016/j.envsci.2015.08.012*

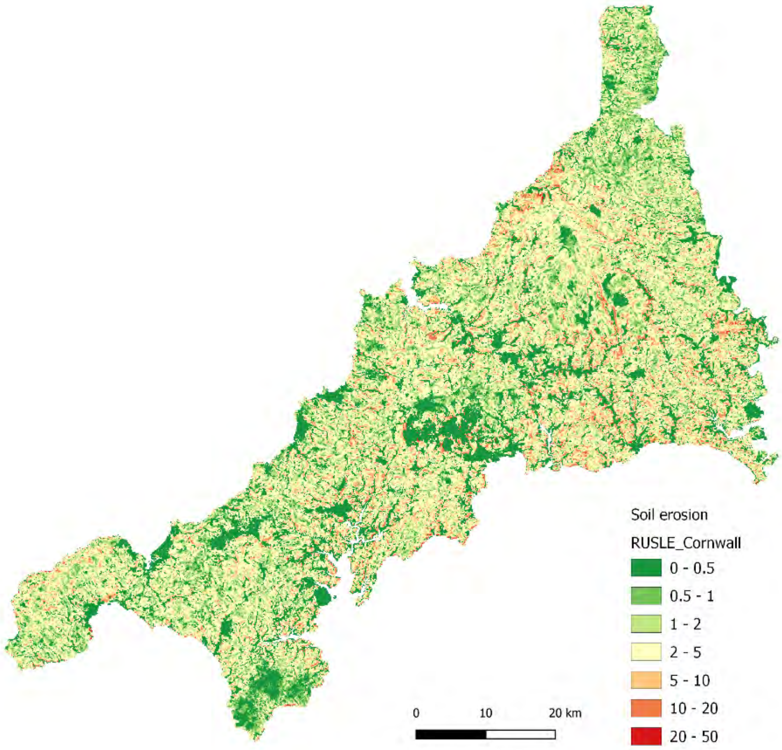
[152] *Borrelli et al. (2017) A new assessment of soil loss due to wind erosion in European agricultural soils using a quantitative spatially distributed modelling approach. Land Degradation & Development 28: 335–344, DOI: 10.1002/ldr.2*

Soil erosion by water

Once exposed through overgrazing, poaching or lack of ground cover in winter months, soil erosion by water is one of the major pathways to soil loss. The European Soil Data Centre[153] mapped the estimated tonnes of soil eroded by water per ha per year for every 100m^2 across the EU. EU Maps of soil erosion by water use the Revised Universal Soil Loss Equation combining factors such as rainfall, soil, topography, land use and management to estimate levels of soil erosion (Panagos et al 2015a[154]; European Soil Data Centre[155]). Using the European Soil Data Centre predicted 'erosion by water' dataset suggests that average soil erosion by water was 2.78 t/ha/yr for the coastal corridor, slightly lower than that for Cornwall as a whole (2.73 t/ha/yr). However, as shown by Map 8, large areas of the coast still experience predicted erosion rates of over 5 t/ha/yr (double the average for Europe) particularly along the south coast, around Falmouth, Tamar estuary, Looe, St Martin, Saltash, Fowey, Megavisey and Gorran Haven, Truro and in the north around Bude, Camel Estuary, and Wadebridge. These areas have the highest potential to benefit from changes to land management to reduce soil loss. Using average soil loss by water per ha suggests that the coastal corridor could be seeing a total average soil loss by water of around 180,182 tonnes per year, and Cornwall 1,018,990.08 tonnes per year on average.

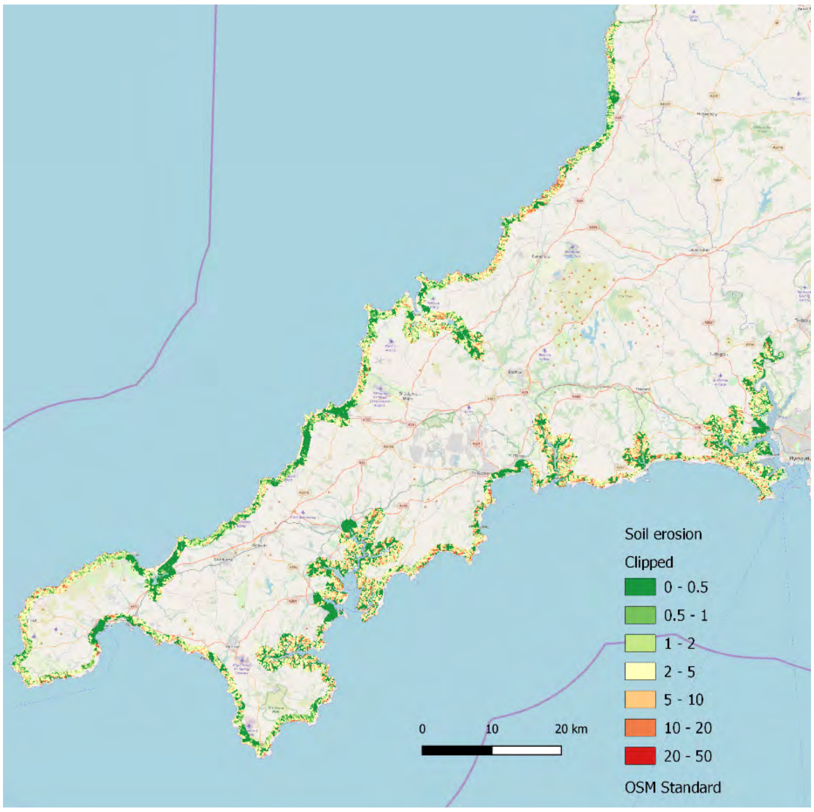
Statistics	Coastal Corridor	Cornwall
Min	0	0
Max	28.44	31.78
Average	2.78	2.82
St.dv	3.12	2.73

Table 78. Soil erosion by water (European Soil Data Centre, esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre)

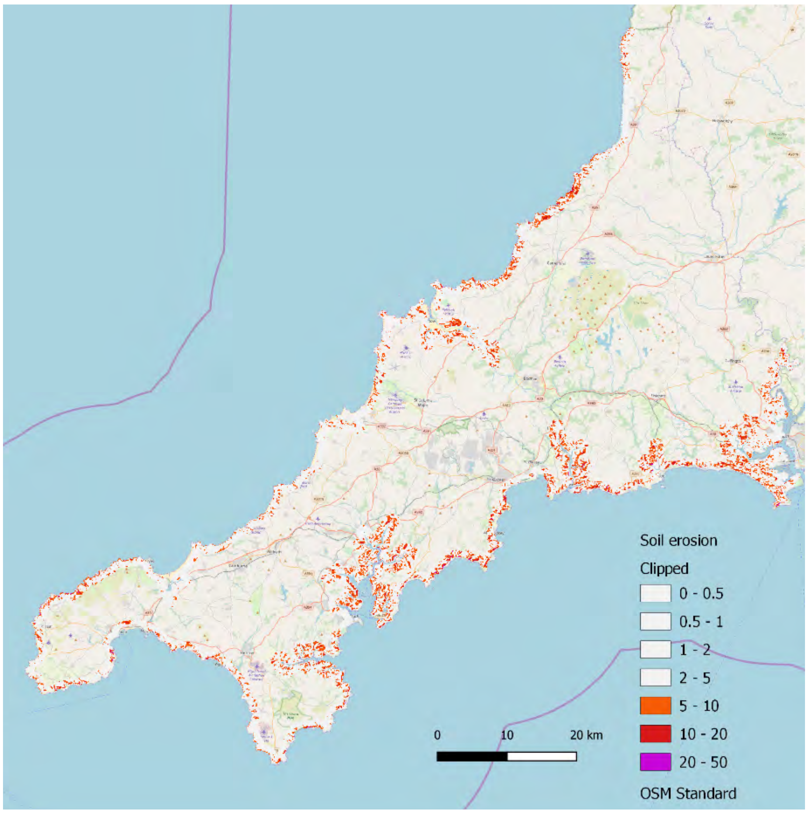


Map 8. Soil erosion by water (t/ha/yr) (Source RUSLE 2016 European Soil Data Centre (ESDAC), esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre)

[153] https://esdac.jrc.ec.europa.eu/content/soil-erosion-water-rusle2015#tabs-0-description=0
[154] *Panagos et al. (2015) The new assessment of soil loss by water erosion in Europe. Environmental Science & Policy 54: 438-447. DOI: 10.1016/j.envsci.2015.08.012*
[155] https://esdac.jrc.ec.europa.eu/



Map 9. Soil erosion by water (t/ha/year) in the coastal corridor (Source RUSLE 2016 European Soil Data Centre (ESDAC), esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre)



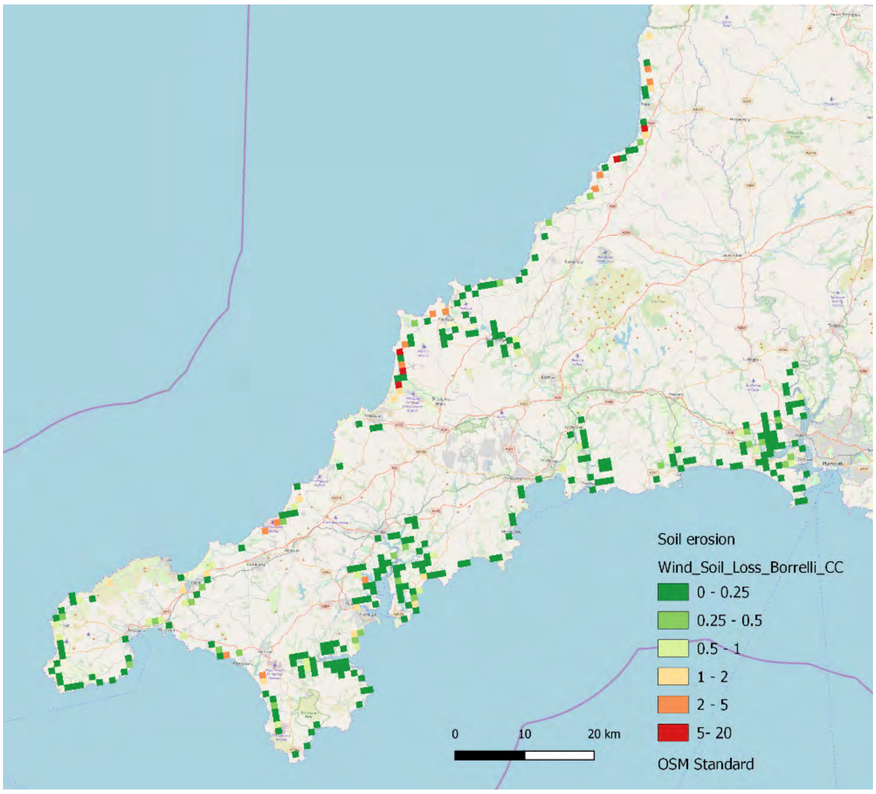
Map 10. Highest rates of soil erosion by water (purple, red, orange): Areas of the coastal corridor with high levels of soil erosion by water (t/ha/year) (Source RUSLE 2016 European Soil Data Centre (ESDAC), esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre; OS Map)

Soil erosion by wind

Soil erosion by wind is a particular issue for arable lands and more arid areas. The European Soil Data Centre provides data on the susceptibility of soil to erosion by wind across Europe, to help increase understanding of when, where and how heavily wind erosion is affecting European arable lands. The dynamics of soil erosion by wind are complex, the European Soil Data Centre's soil loss by wind erosion dataset is based on the Revised Wind Erosion Equation, which employs large scale, wind erosion modelling to evaluate soil loss potential at a 1km^2 resolution (Borelli et al 2017). A complete description of the methodology and the application in Europe is described in Borrelli et al (2017[156]). Using the European Soil Data Centre's dataset, the coastal corridor has a mean soil erosion by wind rate almost four times that of the Cornwall as a whole. Notably, the highest levels of predicted erosion of soil erosion by wind in the coastal corridor are around Newquay airport, Padstow, Crackington Haven to Bude areas. Estimates of potential soil loss by wind for the whole of the coastal corridor, using mean t/ha/yr, suggest that there is a potential loss of around 27,870 tonnes of soil per year in the coastal corridor, some 45% of total estimates of erosion by wind for the whole of Cornwall.

Statistics	Coastal Corridor	Cornwall
Min	0	0
Max	16.38	16.38
Mean	0.43	0.168
St.dv	1.33	0.63

Table 79. Soil erosion by wind (t/ha/yr) (Borelli et al 2017)



Map 11. Potential soil erosion by wind in the coastal corridor (Borrelli et al. 2017)

Air quality mitigation

- *Cornwall has one of the highest amounts of air pollutant (66kg/ha/yr) removal by vegetation in England (ONS 2019[157]).*

---

[156] Borrelli et al. (2017). A new assessment of soil loss due to wind erosion in European agricultural soils using a quantitative spatially distributed modelling approach. Land Degradation & Development 28: 335-344, DOI: 10.1002/ldr.2

[157] https://www.ons.gov.uk/economy/environmentalaccounts/articles/ukairpollutionremovalhowmuchpollutiondoesvegetationremoveinyourarea/2018-07-30

- *In 2015 the coastal corridor and its immediately surrounding area potentially removed an estimated 6,279,357 kg of air pollutants (including ammonia, nitrogen dioxide, ozone, PM10, PM2.5, sulphur dioxide). The average kg removed per km² is however lower in the coastal corridor than in the rest of Cornwall.*
- *The coastal corridor and its immediately surrounding areas are responsible for the removal of an estimated 25% of all air pollutants removed by vegetation in Cornwall (this is not restricted to the 1km strip).*
- *The highest performing areas for air pollution removal by vegetation in the coastal corridor are close to Wadebridge, Tehidy, Mylor Bridge, Looe, Helford Passage, St Germans and Seaton.*

Poor air quality can have a number of adverse health impacts for usual residents. Although air quality is generally good across Cornwall, there are a number of hotspots where air standards fail to meet national air quality objectives. Poor air quality in Cornwall is thought to be due to the volume of traffic congestion, the street canyon effects, or a combination of these factors (Cornwall Council 2018[158]). Nine air quality management areas have been declared across Cornwall, including Camborne, Pool and Redruth (AQMA declared in 2005), Bodmin (AQMA declared 2008), Tideford (AQMA declared 2011), Gunnislake (AQMA declared 2014), St Austell (AQMA declared 2014), Truro (AQMA declared in 2015), Camelford (AQMA declared in 2017), Grampound (declared 2017) and Launceston (declared 2018).

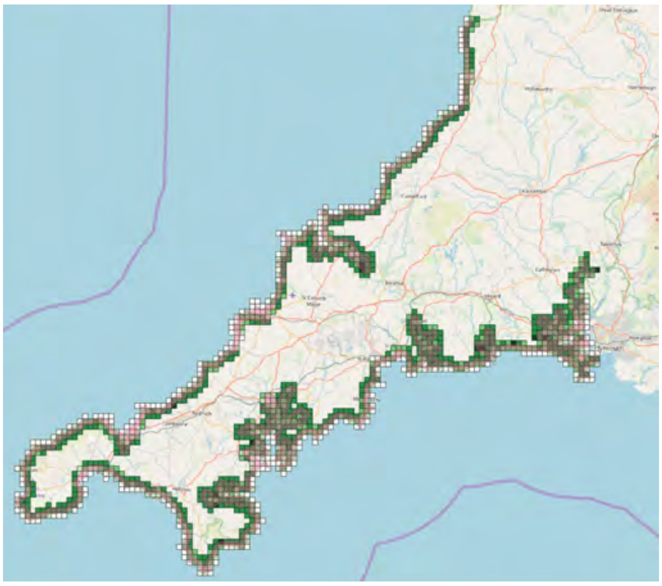
Plants and trees can play a central, and often unrecognised, role in the regulation of key pollutants, including particulate matter (≤10μm in diameter) (PM10) and sulphur dioxide (SO2) (Jones et al 2019[159]). Vegetation helps remove pollutants from the air primarily by intercepting airborne particulates (especially PM10), which are then deposited on surfaces such as leaves and bark, and also by absorbing ozone, SO2 and NOX via stomatal uptake (Bignal et al. 2004[160]). Different amounts of pollutants can be absorbed by different vegetation types and extrapolated to different habitats. Air purification capacity estimates are based on the relative ability of vegetation to trap airborne pollutants or ameliorate air pollution. The highest rates of PM_{10} absorption are by woodland ecosystems, particularly coniferous woodland (ONS 2019). For the UK as a whole, woodlands are estimated to account for over 80% of all PM2.5 removed from the air by vegetation (ONS 2019).

Estimates of the capacity of vegetation in the coastal corridor to contribute to air quality improvements were made based on the ONS and the CEH's national map of pollution removal by vegetation (ONS 2019[161]). On average 66kg of pollutants are potentially removed by vegetation per ha/yr in Cornwall, this is one of the highest amounts of all UK regions (ONS 2019). In 2015, the coastal corridor and its immediate surrounding area are estimated to have potentially removed some 6,279,000kg of pollutants from the air (Table 80), this equates to 25% all pollutants removed from the air by vegetation in 2015 in Cornwall. The highest performing areas were close to Wadebridge, Tehidy, Mylor Bridge, Looe, Helford Passage, St Germans and Seaton.

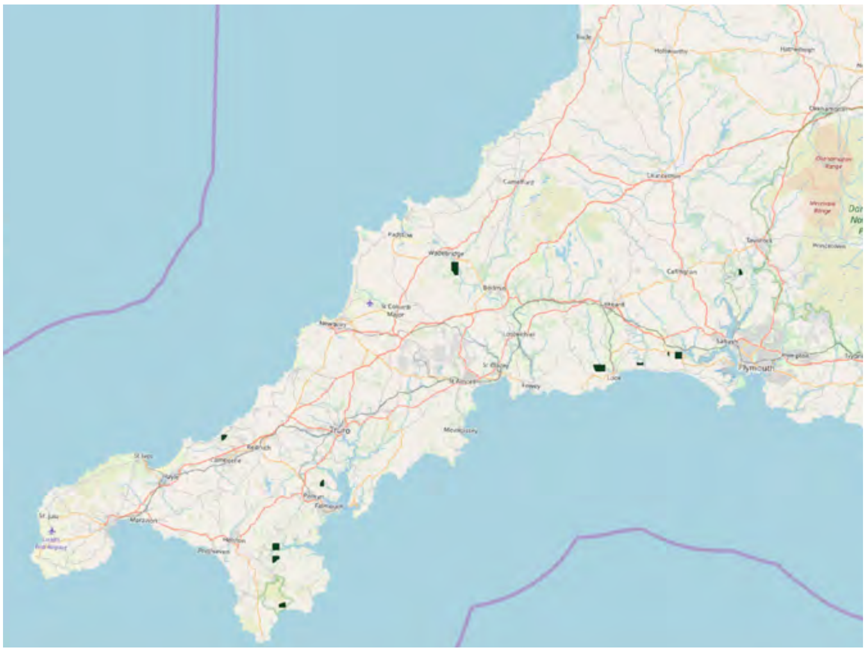
Kilograms of pollutants removed by vegetation in 2015	Coastal Corridor	Rest of Cornwall	Cornwall
Ammonia (NH3)	138665	552104.4	690769.4
Nitrogen Dioxide (NO2)	67964.72	184253.4	252218.1
Ozone (O3)	5602988	16267362	21870350
Particulate Matter (PM10)	225474.4	580382.1	805856.5
Fine Particulate Matter (PM2.5)	96521.62	270183.3	366704.9
Sulphur Dioxide (SO2)	147742.8	455978.8	603721.7
Total (All pollutants)	6,279,357	18,310,264	24,589,621
Average kg removed per ha	51	66	62

Table 80. Air pollution removal by vegetation in the coastal corridor (ONS 2019)

[158] Cornwall Council 2018 https://www.cornwall.gov.uk/media/35432115/cornwall-council-asr_2018-final.pdf
[159] Jones et al. (2019) Natural capital accounting and air quality removal; https://www.charteredforesters.org/wp-content/uploads/2019/01/Jones-et-al-Natural-capital-accounting-of-the-air-quality-regulating-....pdf
[160] Bignal et al. (2004) The ecological effects of diffuse air pollution from road transport. English Nature Research Report 580.
[161] ONS and CEH (2019) https://www.ons.gov.uk/economy/environmentalaccounts/articles/ukairpollutionremovalhowmuchpollutiondoesvegetationremoveinyourarea/2018-07-30



Map 12. Areas included in the coastal corridor analysis of potential for air pollution removed by vegetation (Source: ONS 2019, UK Air Pollution Removal Geopackage[162])



Map 13. Highest performing areas for air pollution removal by vegetation in the coastal corridor (Source: ONS 2019, UK Air Pollution Removal)

Noise regulation

- *Given the concentration of urban areas and high human population density it is anticipated that natural capital assets in the coastal corridor (particularly broadleaved woodlands and scrub habitats) perform significant noise regulation services for usual residents, however, it has not been possible to quantify these benefits.*

Noise associated with traffic, centres of human population and urbanisation, is a recognised public health issue (Berglund et al 1999[163]; HPA 2010[164]), which can have negative effects on human welfare in terms of health and wellbeing. Physiological symptoms

[162] https://www.ons.gov.uk/economy/environmentalaccounts/articles/ukairpollutionremovalhowmuchpollutiondoesvegetationremoveinyourarea/2018-07-30

of noise can manifest in different kinds of stress reactions, increased blood pressure, increased risk of coronary artery disease and disturbances in the immune system. The World Health Organisation estimated that over 50% of the UK population lives in dwellings exposed to noise levels exceeding guideline values, with a health cost of some £2 billion, alongside additional costs associated with 'annoyance' and lost productivity. The UK Health Protection Agency (HPA 2010[165]) estimates that 10% of the population lives in areas of excessive daytime sound levels, and found that up to 30% of the population expresses dissatisfaction in surveys of their local noise environment. Noise pollution can also have negative ecological consequences for wildlife (Tennessen et al 2014[166]).

The capacity of vegetation to regulate or attenuate noise is a recognised ecosystem service (Bolmund and Hunhammar 1999[167]) and is particularly significant in vegetation occurring around towns and cities. Natural vegetation can regulate noise pollution through intercepting noise and reducing the reflection of noise. Different habitat types vary in their effectiveness in attenuating noise, relating to the structure, size and density of vegetation they contain (Fang and Ling 2005[168]) (e.g. Table 80). Wide, complex, dense and high vegetation (trees and shrubs) is particularly effective, for example, every 30m of woodland has been found to reduce noise by 5-10 decibels (Cook & Haverbeke 1972), while evergreen vegetation provides more enhanced noise reduction year-round. As shown in Table 80, coniferous woodland, broadleaved woodland, scattered trees and scrub habitats all have a high potential to regulate noise.

Under the time constraints of this project, it has not been possible to produce detailed noise reduction potential maps for the coastal corridor. However, given the concentration of urban areas and high population density, it is anticipated that natural capital assets in the coastal corridor (particularly broadleaved woodlands and scrub habitats) perform significant regulation of noise pollution for usual residents.

Habitats	Noise Regulation Value
Coniferous Woodland	100
Woodland Broadleaved	80
Scrub (all)	40
Scattered trees all	40
All other green spaces	10
Hedges and Walls	5
All manmade	0

Table 80. Noise regulation potential scored for different habitat types as used in the ECoServGIS model[169]. Habitat age and management is not considered.

Freshwater Quality

- *Cornwall faces a number of significant water quality issues as a result of historic mining actives, industry, development and agricultural practices.*
- *Wetland areas in the coastal corridor are also likely to play a significant role in water quality regulation through denitrification, nitrification and mineralisation of pollutants (e.g. Maltby et al. 2011[170]). There is also an increasing body of evidence that sand dunes and shingle can help to reduce diffuse pollution in the marine environment with positive outcomes on bathing water quality.*
- *The potential of natural capital assets in the coastal corridor to regulate water quality is relatively low, just 2332 ha are scored as having any capacity to deliver water quality benefits, equating to just 3.5% of the coastal corridor (Mosedale et al. 2019 in prep). Furthermore, the majority (49%) of this area only has a low capacity to deliver benefits (Mosedale et al. 2019 in prep).*
- *Areas with concentrated potential to provide improvements in water quality capacity include Marazion, St Ives, Porthleven, Treen, Lamorna, Hayle to Porthreath, Truro, Devoran, Perranaworthal, Ruan Lanihorne, St Austell to Par, Seaton, Hatt, Boscastle, Coombe (Bude), Marsland wood, Perran beach.*

Water quality refers to the biological, chemical and physical makeup of water resources. Good water quality is critical to human and ecosystem health, whilst poor water quality will alter ecosystems, endanger human health and can cause economic damage. A wide

---

[163] *Berglund et al. (1999) Guidelines for community noise. World Health Organization. https://apps.who.int/iris/handle/10665/66217*
[164] *Health Protection Agency (2010) Health protection legislation guidance 2010*
[165] *HPA (2010) https://webarchive.nationalarchives.gov.uk/20100716121707/http://www.hpa.org.uk/web/HPAwebFile/HPAweb_C/1246433634856*
[166] *Tennessen et al. (2014) Traffic noise causes physiological stress and impairs breeding migration behaviour in frogs. Conservation Physiology 2: cou132. doi: 10.1093/conphys/cou032*
[167] *Bolund, P. & Hunhammar, S. 1999. Ecosystem services in urban areas. Ecological Economics 29: 293-301.*
[168] *Fang and Ling (2003) Investigation of the noise reduction provided by tree belts. Landscape and Urban Planning 63:187-195*
[169] *Winn, et al. (2015)* EcoServ-GIS Version 3.3 (Great Britain): A toolkit for mapping ecosystem services*. User Guide. The Wildlife Trusts.*
[170] *Maltby and Acreman (2011) Ecosystem services of wetlands: pathfinder for a new paradigm. Hydrological Sciences Journal, 56 (8): 1341-1359.*

range of factors influence water quality, including pollutants released through industrialisation, climate change, manufacturing and agricultural production, and '*the complex interactions of climate, topography and geology, land cover and management, and other anthropogenic modification of the landscape*'. Water quality is not an ecosystem service in itself (Braunman et al 2007[171]), however, natural capital assets have the capacity to deliver water purification services by absorbing or filtering pollutants or by a physical process such as vegetation preventing or reducing erosion (Lautenbach et al 2012[172]). For example, the targeted planting of woodland close to pollutant sources and pollution delivery pathways have been shown to reduce diffuse pollution (Nesbet et al 2011[173]). These water purification services delivered by natural capital assets can take place during overland flow, infiltration, leaching, groundwater passage or in wetlands or water bodies (Lautenbach et al 2012). There are a wide range of knock-on benefits of delivering improved water quality, including aesthetic and recreation benefits, decreasing water treatment costs, and supporting fish stocks for commercial or recreational purposes (Loomis 2000[174]).

Cornwall faces a number of significant water quality issues. One of the most significant for surface and groundwater quality is the history of mining in Cornwall, and discharges from abandoned mines impact heavily on the quality of rivers, such as the Red River, River Carnon and River Cober, and also on the quality of the groundwater. Commercial farming in Cornwall also causes diffuse pollution (mainly Phosphorous and Nitrate) from agricultural run-off which has a major impact on water quality. Cornwall has designated shellfish areas in the Fal, Fowey, Camel, Helford and Tamar estuaries likely to be impacted by changes in water quality. Substantial areas of Cornwall are designated as Nitrogen Vulnerable Zones.

Research on ecosystem services mapping by Natural England indicates that the habitats, and associated underlying soils, which contribute most to the regulation of water quality include freshwater, broadleaf, mixed and yew woodland, coniferous woodland and supra-littoral sediment (Dales et al 2014[175]). Woodland, scrub and bracken have been found to help to regulate diffuse pollution. Agricultural assets are more likely to have negative effects on water quality. There is an increasing body of evidence that sand dunes and shingle also help to reduce diffuse pollution in the marine environment with positive outcomes on bathing water quality. UK specific research is however lacking. Notably, wetland areas in the coastal corridor are also likely to play a significant role in water quality regulation through denitrification, nitrification and mineralisation of pollutants (Maltby et al. 2011; Van der Wal et al. 2011[176]).

Sub habitat type	Score
Littoral rock	3
Littoral sediment	3
Supra-littoral rock	3
Supra-littoral sediment	3
Arable and horticulture	1
Improved grassland	1
Neutral grassland	1
Freshwater	3
Fen, Marsh & Swamp	2
Bog	2
Dwarf shrub heath	2
Inland rock	2
Montane habitats	2
Acid grassland	2
Calcareous grassland	2
Rough low-productivity grassland	2
Built up areas and gardens	1
Broad leaved, mixed, & yew woodland	3
Coniferous woodland	3

Table 81. Water Quality Scores for Habitat Types (Source: CEH Assessing potential to map ecosystem services Dales et al. 2014)

Water quality is monitored by the EA under the Water Framework Directive (WFD). Between 2009 and 2013 no river in Cornwall was classed as having high water quality under the WFD (Environmental Growth Strategy 2016). Looking at the three river management catchments in Cornwall reveals differences in water quality issues across Cornwall (EA 2011[177]).

West Cornwall and the Fal

There are 127 river water bodies, with a combined length of almost 740km, and eight lakes in the West Cornwall and Fal catchment. 27% of these waters (154km or 21% of river length and three or 38% of the lakes) achieve good or better ecological status/potential (EA 2011). Rivers at good ecological status include the Newlyn River and the Zelah Brook. 44% of waters assessed for biology are at good or high biological status (EA 2011). The main reasons for less than good status are, in order, high levels of copper and zinc, physical modifications, impacted invertebrate and fish communities and high levels of phosphate. These are caused by mining and quarrying, agricultural and rural land management

[171] Braunman et al (2007) *The nature and value of ecosystem services: an overview highlighting hydrologic services. Annu Rev Environ Resour, 32: 67-98.*[Crossref], [Web of Science ®], , [Google Scholar]
[172] Lautenbach et al (2012) https://www.tandfonline.com/doi/full/10.1080/21513732.2011.631940
[173] *Nisbet et al. (2011) Woodland for Water: Woodland measures for meeting Water Framework Directive objectives. Forest Research Monograph, 4, Forest Research, Surrey, 156pp.*
[174] *Loomis (2000) Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. Ecol Econ, 33(1): 103-117.*
[175] *Dales et al. (2014) Assessing the potential for mapping ecosystem services in England based on existing habitats. Natural England Research Reports, Number 056*
[176] *Van der Wal et al. (2011) Mountains, Moorlands and Heaths. UK National Ecosystem Assessment. The UK National Ecosystem Assessment Technical Report. UNEP-WCMN, Cambridge, pp. 105–159.*
[177] *EA (2011) Water for life and livelihoods: River basin management plan SW River Basis District, EA report, Available at:* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/292791/gesw0910bstp-e-e.pdf

challenges, industry, domestic and general public issues, water utility issues, urban and transport issues. Water bodies which have bad or poor ecological status include the Loe, Poltesco River, Porthleven Stream, Carminowe Creek and Cury River (EA 2019).

North Cornwall, Seaton, Looe and Fowey Catchment

There are 99 river water bodies in the North Cornwall, Seaton, Looe and Fowey catchment, with a combined length of almost 600 km, and four lakes. There are significant abstractions in the area for hydroelectric generation, aquaculture and agriculture as well as public water supply. The Colliford Reservoir is an important source of public water supply. An estimated 44% of these waters (219 km or 37% of river length, but none of the lakes) achieve good or better ecological status/potential. Rivers at good status include the upper Fowey and large parts of the River Camel. The main reasons for less than good status are impacted fish communities, physical modifications, and high levels of copper, phosphate and zinc. Water bodies which have bad or poor ecological status include sections of Lower River Strat, Lower River, Benny Stream, Fowey, Crackington Stream, Valency, Gannel (Upper). Colliford Lake, Siblyback Lake, Dozmary Pool, Lerryn River, Warleggan River, Menalhyl, Polmorla Stream, Amble, Issey Brook, Camel, Polperro River, Seaton, West Looe River and many more.

Tamar Catchment

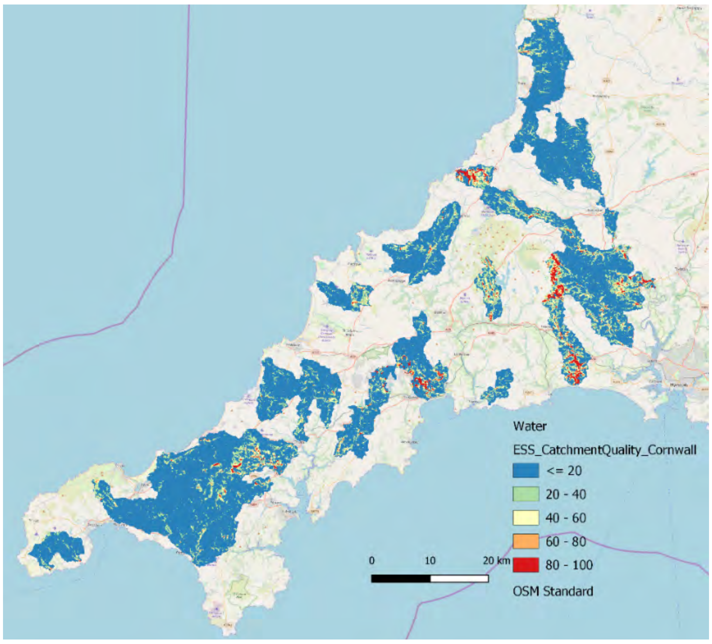
There are 96 river water bodies in the Tamar catchment, with a combined length of just over 800 km, and four lakes. An estimated 39% of water bodies are in good ecological status (EA, 2011). Rivers at good ecological status include most of the river Ottery, Caudworthy Water and the Kensey. The main reasons for less than good status are impacted fish communities, physical modification, high levels of copper, phosphate and an impacted diatom community. Water bodies which have bad or poor ecological status include sections of Upper Tamar Lake, river Deer, Tala Water, Upper River Tamar, Derril Water, Lower Tmar Lake, Lamberal Water, Tala Water, Caudworthy Water, Withey Brook, Tory Brook, River Yealm, River Inny, Tamar (Kelly Brook)

Capacity of natural capital assets to deliver water quality benefits

The potential of natural capital assets to regulate water pollution have been mapped for Cornwall through the SWEEP Mainstreaming Environmental Growth Project (Mosedale et al 2019 in press). Water quality ecosystem service capacity mapping combines factors which cause pollution (such as soil erosion and agricultural surface water runoff), with factors known to reduce pollution through minimising bank erosion, soil loss, slow flow, such as land cover type and vegetation characteristics, to provide a score for every 100m^2 cell across Cornwall related to their capacity to improve water quality (See Map 14 and Map 15, Mosedale et al 2019 in press). The maps also take into account beneficiaries of these ecosystem services by identifying potentially vulnerable activities and areas, such as drinking water abstraction zones, bathing waters, aquaculture sites, tourism and recreation sites, water bodies and catchment areas known to be in ‘not good’ ecological status under the WFD, and existing land designation associated with threats to watercourses such as nitrate and phosphate sensitive areas. As shown in Map 15 and Table 82, the potential of natural capital assets in the coastal corridor to regulate water quality is relatively low, just 2332 ha are scored as having some capacity to deliver water quality benefits or 3.5% of the coastal corridor. Furthermore, the majority of this area has only a low potential to deliver improvement in water quality (49%) however some 22% does have a medium-high or high potential, equating to 288 ha. Areas with potential to provide improvements are near to Marazion, St Ives, Porthleven, Treen, Lamorna, Hayle to Porthreath, Truro, Devoran, Perranaworthal, Ruan Lanihorne, St Austell to Par, Seaton, Hatt, Boscastle, Coombe (Bude), Marsland wood, Perran Beach.

Water Quality Capacity Score	Score range	Area (ha)	%
Low	1 – 20	1,150	49%
Low – Medium	20 – 40	655	28%
Medium	40 – 60	239	10%
Medium- High	60 – 80	126	5%
High	80 - 100	162	7%
Total		2,332	

Table 82. Area of the coastal corridor with the capacity to regulate water quality (Mosedale et al 2019 in press)



Map 14. Capacity of land to aid water quality improvements (blue low, red high) (Mosedale et al 2019 in press)

Map 15. Capacity of land to aid water quality improvements (blue low, red high) (Mosedale et al 2019 in press)

Bathing water quality

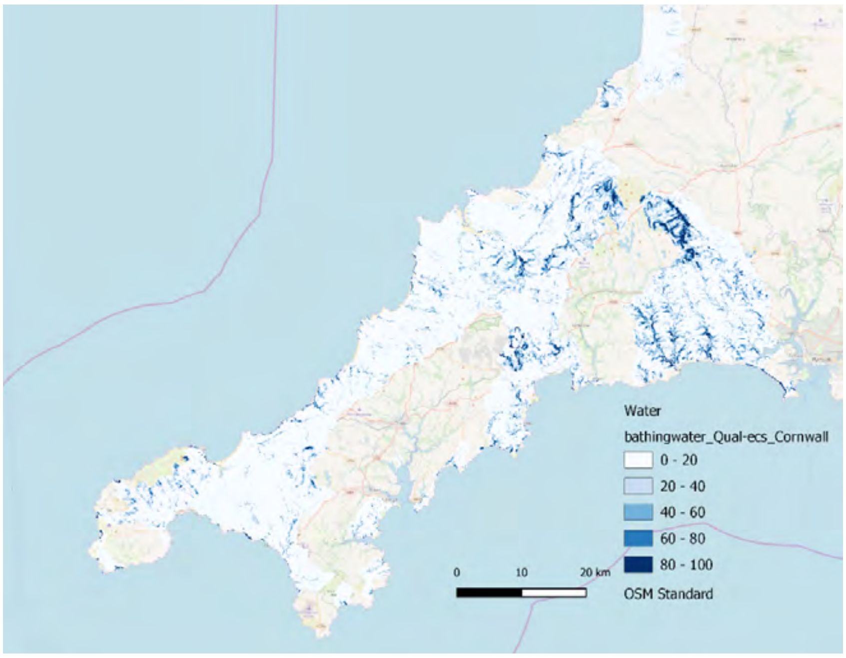
- *Bathing water quality influences the potential for recreational use. Much like freshwater quality, natural capital assets can help to improve bathing water quality by reducing pollution from surface and ground waters.*
- *19% of the coastal corridor was found to have some capacity to deliver benefits for bathing water quality through land use or management changes, equating to around 12,662 ha. The majority of this area (50%) only had a low potential to deliver benefits with just 11% having the potential to deliver medium-high to high benefits, some 1382 ha.*

People visiting a beach use the water for a variety of activities including bathing and marine recreation. Bathing water quality influences the potential for recreational use. Monitoring of bathing water quality aims to safeguard public health and ecosystems. "*A bathing water is defined as a beach (or inland site) used by a large number of bathers or where bathing is promoted or associated* *facilities are provided*" (Marine Conservation Society 2019[178]). Not all waters are classed as bathing waters, and in Cornwall there are around 90 designated bathing waters. Water quality is only monitored at popular beaches which are called '*designated bathing waters'*. The major sources of bathing water pollution are sewage and water draining from farms and farmland. These sources of pollution generally increase during heavy rains and floods due to sewage overflow and polluted drainage water being washed into rivers and seas. The EU's revised Bathing Water Directive specifies if bathing water quality can be classified as 'excellent', 'good', 'sufficient' or 'poor' depending on the levels of faecal bacteria detected.

Much like freshwater quality, natural capital assets can help to improve bathing water quality by reducing pollution from surface and ground waters. The potential of natural capital assets to regulate bathing water pollution have been mapped for Cornwall through the SWEEP Mainstreaming Environmental Growth Project (Mosedale et al 2019 in press). 19% of the coastal corridor was found to have some capacity to deliver benefits for bathing water quality through land use or management changes, equating to around 12,662 ha. The majority of this area (50%) only had a low potential to deliver benefits with just 11% having the potential to deliver medium-high to high benefits, some 1382 ha. Areas with the greatest potential are close to Looe, Saltash, Fowey to St Blazey, Gorren Haven, Castle wood, Carne Beach, St Anthony Head, Mawana Smith/Helford/passage, Helford, Parthhallow, Manacle point and Dean Quarries, Kennack Sands, Mullion, Rinsey, Treen, Sennan, Portheras Cover, St Ives, Hells mouth to Perranporth, Wadebridge and Crackington Haven.

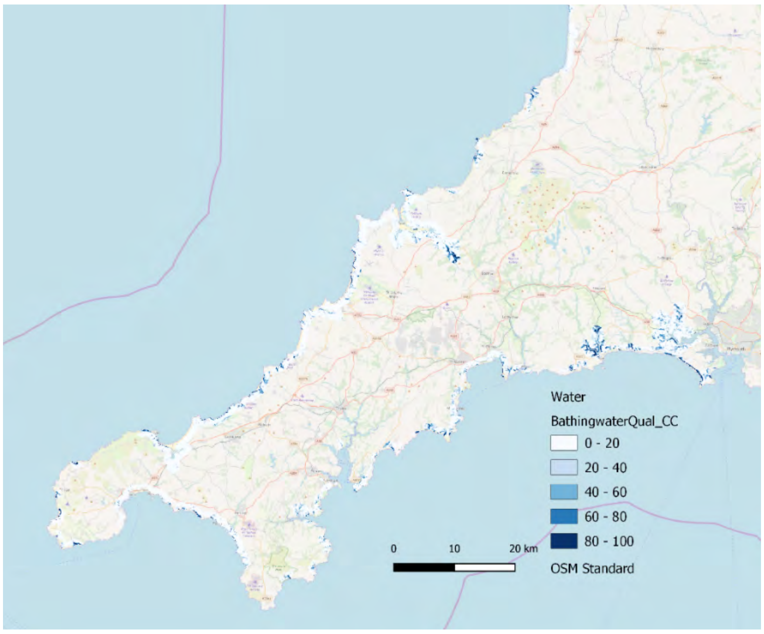
Bathing water Capacity Score	Score range	Area (ha)	%
Low	1 – 20	6268	50%
Low – Medium	20 – 40	3549	28%
Medium	40 – 60	1463	12%
Medium- High	60 – 80	778	6%
High	80 - 100	604	5%
Total		12662	

Table 83. Area of the coastal corridor with capacity to regulate bathing water quality (Mosedale et al 2019 in press)



Map 16. Capacity to influence bathing water quality (Mosedale et al. 2019 in press)

[178] https://www.mcsuk.org/clean-seas/bathing-water-facts



Map 17. Coastal corridor capacity to influence bathing water quality (Mosedale et al. 2019 in press)

Water Flow Capacity

- *The UK NEA (2011) identifies coastal margins as playing an important role in storing and slowing the flow of surface water runoff.*
- *The capacity of the land to mitigate flood risk is much less in the coastal corridor than in other areas in Cornwall. The majority of natural capital assets with high flood mitigation potential are around NW and central Cornwall (Mosedale et al 2019 in press).*
- *Some 29,808 ha of the coastal corridor has some potential capacity to deliver flood mitigation benefits, almost 45% of the coastal corridor. 132 ha of the coastal corridor has 'high' potential to deliver flood mitigation benefits. However, the vast majority of this area (93%) only has a low potential to deliver flood mitigation benefits (Mosedale et al 2019 in press).*
- *Spatially some of the highest scoring areas in the coastal corridor for flood mitigation potential are immediately upstream from Wadebridge, close to Mousehole, Porthreath, between Penryn and Falmouth, and at Looe (Mosedale et al 2019 in press).*

Water flow capacity is the capacity of natural capital assets to slow water runoff and thereby contribute to flood alleviation. The extent and severity of flood events depend on the rate at which rainfall accumulates on the ground's surface and is transferred to rivers. There is an increasing body of evidence supporting the role of natural vegetation, topography, soil structure and land use in the mitigation of downstream flood risk (EA 2019[179]). Land cover and vegetation affect surface runoff rates by intercepting rainfall, evapotranspiration, and improved soil infiltration. By slowing and intercepting overland surface flow, natural capital assets can act to moderate extreme events by increasing the runoff time and reducing the magnitude of downstream peak flows. More impervious surfaces and certain agricultural land uses (including overgrazing, ploughing and crop production) lead to soil compaction and reduced rates of water infiltration. Natural capital assets with a higher capacity to slow water transfer include those with high vegetation cover, such as woodlands, scrub, grasslands and wetland. The UK NEA also identifies coastal margins as playing an important role in storing and slowing the flow of surface water runoff (NEA 2011). Higher amounts of vegetation are particularly important for the interception of water flow and increasing the infiltration properties of soils. The location of natural capital assets also affects their capacity to deliver flood mitigation benefits, in particular benefits can be maximised by increasing vegetation in upper catchments, and reducing grazing in other areas, or the creation of buffer strips close to watercourses and field boundaries. In particular, the expansion of wetland and woodlands are seen as crucial to increasing the capacity of the landscape to attenuate surface runoff and increase infiltration.

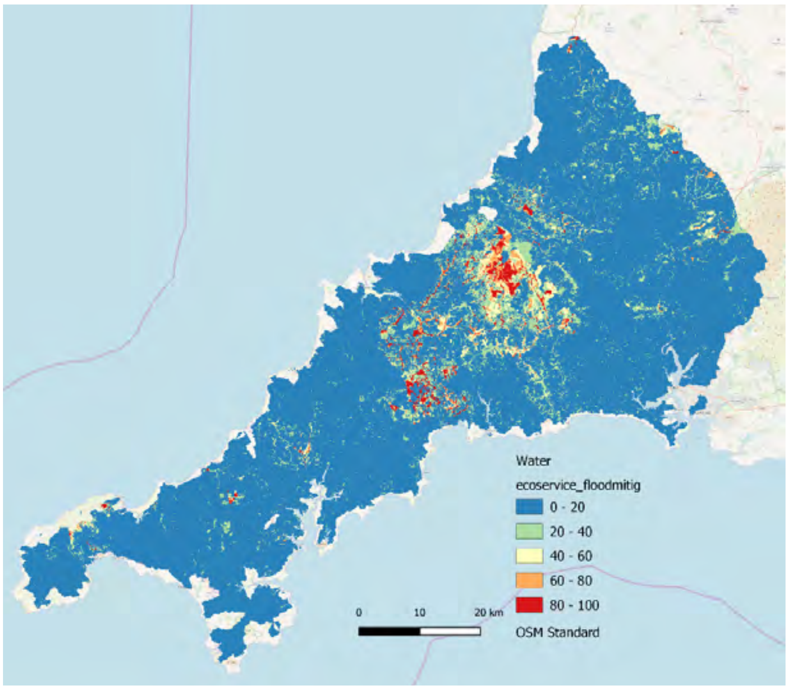
[179] *EA (2019) Evidence Directory - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/654440/Working_with_natural_processes_one_page_summaries.pdf*

The potential of natural capital assets to mitigate flood risk has been mapped for Cornwall through the SWEEP Mainstreaming Environmental Growth Project (Mosedale et al. 2019 in prep). Maps 18 and 19 (Mosedale et al. 2019 in prep) combine estimates of potentially vulnerable areas (i.e. buildings at risk of flooding downstream) with flood mitigation potential (i.e. the potential of land cover to mitigate the risk of flooding). The location of areas potentially vulnerable to flooding (beneficiary areas) has been derived for each grid cell based on where existing built-up areas, or areas assigned to an allocation zone, fall within EA flood risk zones for surface water or rivers/seas flooding with a risk greater than 0.1% per annum (Mosedale et al. 2019 in prep). To map the potential flood mitigation capacity of habitats, Mosedale et al. (2019 in press) score areas based on the potential of different land cover types to intercept surface water runoff, the resistance of land cover to water flow, soil loss and transportation, combined with rainfall erosivity and peak flow velocity. There are number of acknowledged limitations to the flood mitigation capacity map, the main ones include that (i) it does not take account of areas which are already benefitting from flood protection or flood storage areas, (ii) the effects of land management practices are excluded, (iii) the interdependence of landcover effects (or changes) across a catchment area are excluded, (iv) the importance of hedgerows to reduce overland flow is excluded, and (v) watercourse characteristics that could affect flow velocity are not included.

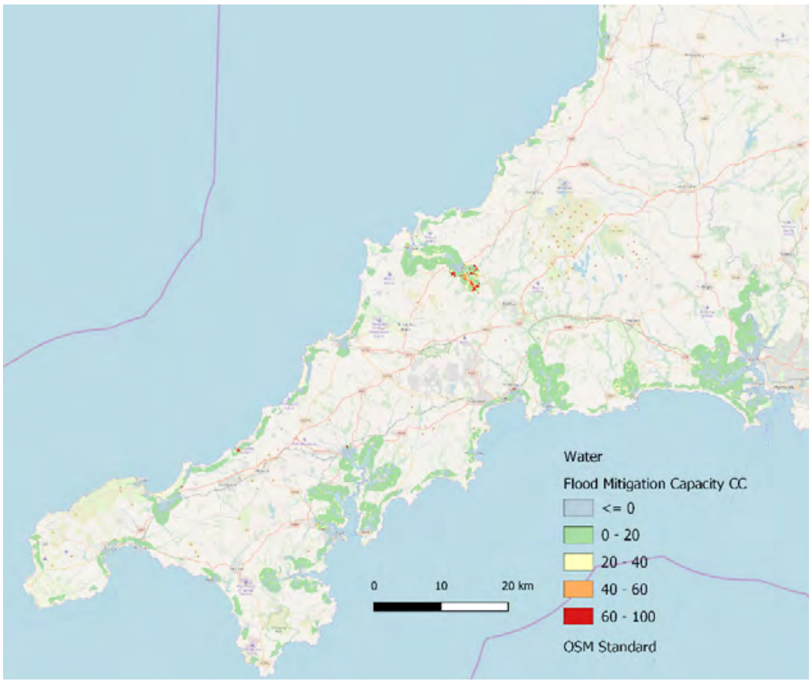
The capacity of the land to mitigate flood risk is much less in the coastal corridor than in other areas in Cornwall. As shown in map 19, the majority of flood mitigation potential is around NE and central Cornwall. Some 29,808 ha of the coastal corridor does have some potential capacity to deliver flood mitigation benefits, almost 45% of the coastal corridor, however the vast majority of this area (93%) only has low such potential. Notably, 132 ha of the coastal corridor has high potential to deliver flood mitigation benefits. Spatially some of the highest scoring areas in the coastal corridor are immediately upstream from Wadebridge, close to Mousehole, Porthreath, between Penryn and Falmouth, and at Looe.

	Scores	Coastal Corridor Area (ha)	%
Low	1 – 20	27,640	*93%*
Low – Medium	20 – 40	1,787	*6%*
Medium	40 – 60	154	*1%*
Medium- High	60 – 80	95	*0.3%*
High	80 - 100	132	0.4%
Total		29,808	

Table 84. Flood mitigation potential in the Coastal Corridor (Mosedale et al. 2019 in prep)



Map 18. Flood mitigation potential in Cornwall (Mosedale et al. 2019 in prep)



Map 19. Flood mitigation potential in the coastal corridor (Mosedale et al. 2019 in prep).

4.02.02 Provisioning Ecosystem Services

Fibre (timber production)

- *Woodlands in the coastal corridor contain an estimated 1,782,212 m^3 standing volume of timber, equating to 20.7% of the total standing stock timber volume in Cornwall.*
- *Under prescribed management conditions, woodlands in the coastal corridor have the potential to generate an estimated 38.5 thousand m^3 per year in annual growth in timber volume (17% of Cornwall's total).*

11.4% (7,400 ha) of the coastal corridor is covered by woodlands (see sections 3.04.04; and 4.01.02). The majority of these woodlands, some 85%, are over 0.5ha in size (NFI 2017[180]). Within the coastal corridor, broadleaved woodlands represent 97% of the resource. Many of these woodlands are privately owned and their management and condition is unknown. Major woodland owners in Cornwall include the Forestry Commission (10%), National Trust, Cornwall Wildlife Trust, The Woodland Trust and the Duchy of Cornwall. Woodlands provide a range of ecosystem services including the provision of fibre or timber, for use in construction, wood chip for board and wood fuel. Other provisioning services from woodlands include non-timber forest products, e.g. tree fruit, foliage, wild deer or livestock raised in woodland, water supply, and biodiversity (Sing et al. 2015[181]). This section estimates the volume of timber (standing timber stock) present in the coastal corridor and estimated annual increases.

Standing Timber Stock Volume

Wood stock volume, or standing stock volume (m^3), of broadleaved and coniferous woodlands, has been estimated for all areas mapped by the Forestry Commission (FC) through the National Forest Inventory (NFI, 2011, 2013) in the coastal corridor and Cornwall. To calculate standing volume in the coastal corridor, NFI standing stock volume estimates for Devon, Cornwall and the Isles of Scilly (FC 2017/6) were applied to the extent of woodland in these two counties to provide an estimated average standing volume (m^3) per ha, following the methodology outlined by Eftec (2015[182]). Average standing volume (m^3) per ha was then summed

[180] NFI (2017) https://www.forestresearch.gov.uk/tools-and-resources/national-forest-inventory/about-the-nfi/
[181] Sing et al. (2015) https://www.forestry.gov.uk/PDF/FCRN020.pdf/$FILE/FCRN020.pdf
[182] Methodological approach as outlined in Eftec (2015) Developing UK Natural Capital Accounts: Woodland Ecosystem Accounts, Report to Defra, Available at: http://sciencesearch.defra.gov.uk/Document.aspx?Document=12480_DevelopingUKNCAccounts_WoodlandEcosystemAccount_FINAL_March2015.pdf

by the total species (broadleaved/coniferous) areas for both Cornwall and the coastal corridor[183], to give a broad estimate of total standing timber volume. Based on average standing volume per ha, woodlands in the coastal corridor contain an estimated physical stock of 1,782,212 m^3 in standing volume of timber. The volume of standing timber in the coastal corridor equates to 20.7% of the total volume in Cornwall.

Species	AVER Standing Volume m^3 per ha	CC total standing vol m^3	Cornwall total standing vol m^3
Coniferous	318.5	69,847.5	1,465,225.9
Broadleaved	238.4	1,712,365.2	7,147,370.3
	TOTAL	1,782,212 m^3[20.7%]	8,612,596 m^3

Table 85. Standing Stock volume estimates for woodlands in the coastal corridor (Source: Forestry Commission 2017)

Annual Yield

There is no available spatial data on the distribution of timber provision across UK woodlands at a subnational level (eftec 2015[184]). In the absence of detailed figures on local timber harvesting, the standing stock of woodlands combined with average annual yield figures (m3 per ha per yr) can be used to provide a crude estimate of how much timber will be produced annually in the coastal corridor, and its approximate value (Eftec 2015). Yields (m3 per ha/yr) are estimated by the FC based on patterns of tree growth and predicted potential productivity which should be expected for forestry stands of different tree species, with varying growth rates, when managed in different ways (FC 2016[185]). Yield classes, calculated by the FC, provide an estimate of the potential productivity of a woodland, in terms of maximum mean annual increment of cumulative timber volume achieved. The FC publishes mean yields for all broadleaved and coniferous woodlands at subregional levels, including for Devon, Cornwall and the Isles of Scilly (FC 2017[186]). Yield estimates are limited as they are designed to be applied to even-aged stands of trees, and have limited application to woodland stands with more complex structure and management, for example, uneven-aged stands of trees. Any deviation from management prescriptions will result in different stand characteristics and yields. It is unclear how much woodland in Cornwall is under active management, but there are suggestions that up to 50% of woodland in the SW is unmanaged. Therefore, yield classes are likely to provide only a crude estimate of annual yield volume in the coastal corridor.

Using local yield estimates suggests that woodlands in the coastal corridor could potentially generate an additional 38.5 thousand m^3 in timber volume growth per year (17% of Cornwall's total). As outlined above, this figure is acknowledged only to be an estimate. As highlighted above it is not understood how much of this woodland is harvested per year and average yield data has been used without knowledge of stand densities and management. However, the CAONB suggests that the total harvesting level across the CAONB (which covers some 60+% of the coastal corridor) has not changed significantly between 1995 and 2015, but the use of harvested resources has changed from chipboard towards wood fuel production (Holzinger and Laughlin 2016). A rudimentary value for the present asset value can be assigned to the annual incremental growth of timber volume in woodlands by combining the annual volume of timber produced (m^3 per year) by the unit value of timber (£ per m^3) (eftec 2015). This suggests a yield value of around £658 thousand per year. To improve this figure, more information on the annual volume of timber removed or harvested each year is needed, along with management. No attempt has been made to project the capacity of woodland to provide timber into the future.

	FC Devon, Cornwall and the Isles of Scilly	Coastal Corridor		Cornwall	
	Average annual yield	Area (ha)	Annual Yield potential m3 per yr	Area (ha)	Annual Yield m3 per yr
Coniferous	15.4 m^3 ha yr	219.3	3,377.1	4,600.2	70,842.3
Broadleaved	4.9 m^3 ha yr	7,182.7	35,195.4	29,980.6	146,904.8
		TOTAL	38,572.5		217,747.1

Table 86. Estimates of timber volume growth per year for the coastal corridor.

[183] Based on the NFI stats for Devon, Cornwall and the Isles of Scilly, FC 2017/6 estimates of the total stocked area of woodland (coniferous and broadleaved) and total standing volume m^3. Coniferous woodland stocked area: 25,900 ha (mapped area); Standing volume 8,251,000m^3 obs. Broadleaved woodland 73,200 (mapped area); Standing volume 17,451,000 m^3 obs

[184] Eftec (2015) Developing UK Natural Capital Accounts: Woodland Ecosystem Accounts, Report to Defra, Available at: http://sciencesearch.defra.gov.uk/Document.aspx?Document=12480_DevelopingUKNCAccounts_WoodlandEcosystemAccount_FINAL_March2015.pdf

[185] FC (2016) https://www.forestry.gov.uk/pdf/FCBK048.pdf/$FILE/FCBK048.pdf

[186] FC (2017) National Forest Inventory Statistics for Devon, Cornwall and the Isles of Scilly: https://www.forestresearch.gov.uk/documents/3000/FR_NFI_statistics_report_DCS_2017.pdf

	Coastal Corridor	Cornwall
	Annual yield value	Annual yield value
Coniferous	£ 102,188[187]	£ 2,143,687
Broadleaved	£ 556,087[188]	£ 2,321,095.8
Total	£658,275	£4,464,782

Table 87. Estimates of the value of timber volume growth per year for the coastal corridor.

Water supply

- *The coastal corridor does not contain any areas likely to influence sensitive surface drinking water supply zones.*
- *The coastal corridor has some significance for groundwater source protection; 328ha of the coastal corridor is classed as a groundwater source protection zone (SPZ) which equates to 16% of Cornwall's total groundwater SPZ.*
- *Three water bodies classed as 'restricted water available' and 'water not available for licencing' intersect with the coastal corridor, including at: Newlyn Commbe River, St Levan Stream, River Kennal, Argal Stream and Bodkiddick stream.*

Natural capital assets are vital for the provision and storage of freshwater resources, for drinking and domestic uses, recreation, power generation, agricultural irrigation and some manufacturing processes. Water supply is the provision of volumes of water independent of its quality (Dales et al 2014[189]). In Cornwall, water abstraction takes place largely for public water supply, but also for mine water treatment, particularly the china clay industry, agriculture, aquaculture, and hydroelectric power generation.

The WWF Water Risk Filter (2019) suggests that some parts of Cornwall are under greater levels of water stress than others, with particularly high risk areas highlighted around Helston and Falmouth, North Tamar, Bodmin, East Cornwall and North of Saltash (WWF 2019[190]). The EA provides further detail on levels of water stress through maps of the availability for additional water for consumptive abstraction for certain water bodies. 89% of the water bodies in Cornwall are classed as '*water available for licencing*', only 9% is classed as '*restricted water available*' and '*water not available for licencing*'. Three water bodies classed as restricted water available' and 'water not available for licencing' intersect with the coastal corridor, including at Newlyn Commbe River, St Levan Stream, River Kennal, Argal Stream and Bodkiddick stream. Drinking Water Surface Water Safeguarded Zones cover some 62,760 ha of Cornwall. However, there are no drinking surface water sensitive zones (i.e. reservoir catchments) within the coastal corridor (Mosedale et al 2019 in press). Some important areas do however lie close to the corridor, at Treen, North River Tamar Estuary and North of Falmouth and Helston.

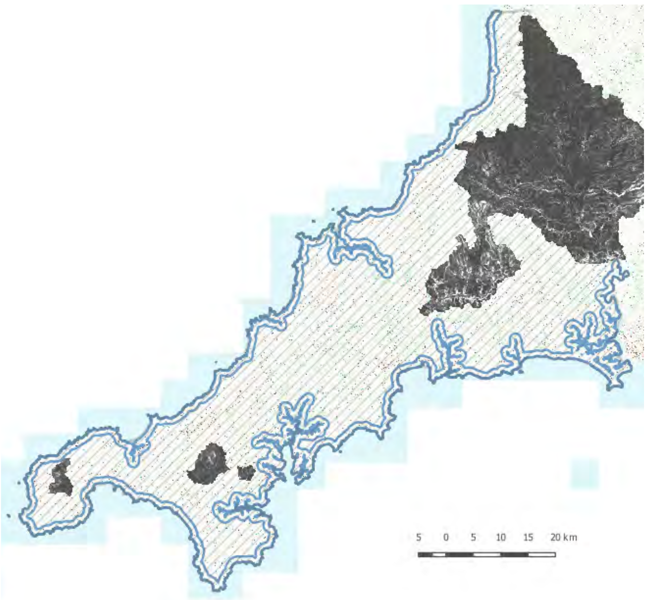
---

[187] *Coniferous woodland areas are more likely to be managed for timber. Average price for softwood in 2017 (Forestry Commission Coniferous Standing Sales price Index (Forestry Commission 2017) inflated for 2018 prices (£30.26). Timber Price Indices - Might be best to take the 5 year average. https://www.forestresearch.gov.uk/tools-and-resources/statistics/statistics-by-topic/timber-statistics/timber-price-indices/*

[188] **The price for broadleaved timber in 2015 ranged from £15 to high quality timber reaching £250 per m3 standing (ABC 2015). For woodlands in Cornwall, broadleaved woodland is assumed to not be managed for commercial forestry and any income would be in the form of woodfuel. The value of woodfuel was estimated using an approximate resource rent based on the market price of woodfuel minus the harvesting, extraction, processing, and transportation costs. (AECOM Dorset) - In 2018 woodfuel price per m3 was £15.80.*

[189] *Dales et al. (2014) Assessing the potential for mapping ecosystem services in England based on existing habitats. Natural England Research Reports, Number 056.*

[190] *WWF (2019) - http://waterriskfilter.panda.org/en/Explore/Map*



Map 20. Important areas for the provision of drinking water (Mosedale et al 2019 in press)

In addition to surface water abstraction, groundwater provides an estimated third of our drinking water in England, and maintains critical water levels in many rivers. Groundwater Source Protection Zones (SPZs) are defined by the Environment Agency (EA) for groundwater sources, such as wells, boreholes and springs, used for public drinking water supply. Groundwater from these SPZ ends up in a public drinking water supply at some point, and therefore it is essential to protect it from contamination by any activities that might cause pollution in the area. SPZs indicate where the risk of contamination from any activities that might cause pollution in the area, in terms of three main zones (inner, outer and total catchment). Mapping of groundwater SPZs in Cornwall indicates that 329ha of the coastal corridor is classed as a groundwater SPZ, equating to 16% of the total groundwater SPZ in Cornwall. Groundwater SPZ are widely distributed across the coastal corridor with sites north of Saltash, near Mylor, Trewithick, St Ives, Upton Towan, Holywell, Boscastle, Budge and Great Winson.

Groundwater Source Protection Zone	CC area (ha)	Count	Cornwall (ha)	Count
Inner Zone	9.6	12	167.9	71
Outer Zone	267.0	11	1357.7	60
TOTAL CATCHMENT	52.1	1	466.4	5
Total Area	328.8	24	1992.0	136

Table 88. Groundwater Source Protection Zones by area in the coastal corridor (EA 2019[191]).

4.02.03 Supporting Ecosystem Services

Pollination

- *The CEH Nectar plant diversity map for bees (Maskell et al 2016[192]) suggests that the coastal corridor has a slightly higher mean value of nectar plant diversity for bees than the average for the whole of Cornwall. Casalegno et al. (2014[193]) also show that the coastal corridor has a slightly higher average habitat availability for pollinators than the rest of Cornwall, with a 5% lower amount of habitat with 'low potential' to provide pollinator habitats and 5% greater coverage of habitats with 'medium potential' to provide pollinator habitats.*
- *The distribution of habitat availability for pollinators shows high concentration around the NW coast of Cornwall particularly around West Penwith, Godrevy and Holywell (Casalegno et al. 2014).*

[191] https://data.gov.uk/dataset/09889a48-0439-4bbe-8f2a-87bba26fbbf5/source-protection-zones-merged
[192] Maskell et al. (2016) Bee nectar plant diversity of Great Britain. NERC Environmental Information Data Centre. http://doi.org/10.5285/623a38dd66e8-42e2-b49f-65a15d63beb5
[193] Casalegno et al. (2014) Regional Scale Prioritisation for Key Ecosystem Services, Renewable Energy Production and Urban Development. PLoS ONE 9(9): e107822. https://doi.org/10.1371/journal.pone.0107822

- *Notably, the coastal corridor contains 81.4% of the highest nectar productivity habitat, calcareous grassland, which is concentrated in one site in the coastal corridor – Holywell.*
- *Estimates of mean nectar productivity per ha (kg of sugars/ha/year) summed by the area of different habitat types suggests that habitats in the coastal corridor have the capacity to produce around 3.94 million kg of sugars per year for pollinators, with a mean nectar productivity of 77.2 kg per ha (Baude et al 2016).*

Pollination services provide crucial support for both food production and for biodiversity, as a range of crop and wild species depend upon insect-mediated pollen transfer. Pollination services contribute to improvements in the quantity and quality of crops, lower costs of crop production, and support successful reproduction of flowers and vegetation in a variety of different habitats (Klein et al. 2007[194]). Some crops are pollinated by managed imported bumblebee populations (e.g. strawberries, tomatoes), while others are much more dependent on wild pollinators (e.g. apples, field beans) (Smith et al 2011[195]; Maskell et al 2016[196]). In the UK, it is estimated that around 20% of crop production is dependent on pollinators and this dependency is increasing with a reported average growth of 54% since 1984 (Breeze et al. 2011[197]). Wild pollinated flowers also make a significant contribution to cultural ecosystem services including aesthetic value, and support biodiversity (Maskell et al 2016).

Pollinator abundance, and visitation rates are higher in certain habitats, e.g. flower-rich grasslands and forest edges (Maskell et al 2016), consequently, habitats can be classified in terms of their potential capacity to provide pollination services. A number of different methodologies have been used to provide an estimation of the potential importance of different habitats/land cover types in the coastal corridor for pollinator species, including the CEH national nectar plant diversity index (Maskell et al 2016). Casalegno et al. (2014) also provide a local assessment of the availability of habitats for pollinators in Cornwall. Nectar productivity, the capacity of habitats to provide nectar for pollinators, has been estimated by broad habitat type by Baude et al. (2016).

CEH Nectar Plant Diversity Index

The CEH nectar plant diversity index (CEH 2014[198]; Maskell et al 2016) estimates the mean bee nectar plant species richness for different habitats, based on a list of important plant species for bumblebees and solitary bees (Maskell et al. 2016) combined with plant survey data from the Countryside Survey 2007[199]. Nectar plant species richness data was then extrapolated across the whole of England, using broad habitat types, combined with data on additional variables such as air temperature, nitrogen deposition, precipitation and altitude, to produce the nectar plant diversity index (CEH 2014; Maskell et al 2016). Using this approach, the CEH nectar plant diversity index was mapped nationally and used to predict distribution and abundance of nectar plants important for bees (Maskell et al 2016). In using the nectar plant diversity index there are a number of acknowledged limitations, for example, urban and littoral rock habitats were not sampled and have no associated data, furthermore, the map resolution was limited at 1km^2. For the coastal corridor, the CEH Nectar plant diversity map indicates that grid squares intersecting or within the coastal corridor have slightly higher means value for nectar plant diversity for bees than the average for the whole of Cornwall.

	Coastal Corridor	Cornwall
Min	2.601	2.47
Mean	6.092	5.923
Max	10.96	10.96
Stand deviation	0.58	0.59

*Table 89. CEH nectar plant diversity for bees (species per 2m x 2m plot) (1km square averages) (*For the coastal corridor this is the approximate value for raster pixels within or intersecting the corridor) (Source CEH 2015)*

Habitat availability for pollinators

Casalegno et al. (2014) produced a 100m x 100m resolution map of habitat availability for pollinators for Cornwall based on Free (1993), Chan (2006), Sharp et al (2014) and Shlup et al. (2014). Casalegno et al. (2014) weighted different habitats for their potential

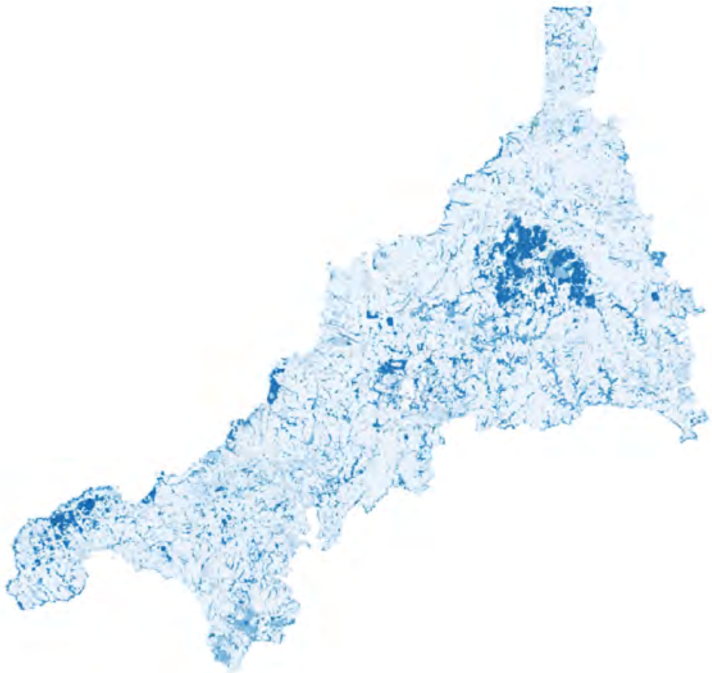
[194] Klein et al. (2006) Importance of pollinators in changing landscapes for world Crops, Proc. R. Soc. B 274: 1608. Available at: https://royalsocietypublishing.org/doi/full/10.1098/rspb.2006.3721
[195] Smith. et al. (2011). Regulating services. In: The UK National Ecosystem Assessment Technical Report. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge.
[196] Center for Ecology and Hydrology (2015) Nectar plant diversity for bees, https://eip.ceh.ac.uk/naturalengland-ncmaps/reports/pollinators.pdf; Maskell et al. (2016). Bee nectar plant diversity of Great Britain. NERC Environmental Information Data Centre. http://doi.org/10.5285/623a38dd66e8-42e2-b49f-65a15d63beb5
[197] Breeze et a.l (2011) Pollination services in the UK: How important are honeybees? Agriculture Ecosystems and Environment 142 (3): 137-143, available at: https://www.researchgate.net/publication/251520349_Pollination_services_in_the_UK_How_important_are_honeybees
[198] CEH (2014) – Pollinator map - https://eip.ceh.ac.uk/naturalengland-ncmaps/reports/pollinators.pdf
[199] Counts of the bee nectar plants per 2m x 2m vegetation plot were extrapolated based on relationships between nectar plant species richness, broad habitat type, air temperature, nitrogen deposition, precipitation and altitude (as key variables affecting nectar plant richness).

to provide pollinator habitat, rescaled to 100m resolution, to provide an indication of location with greater or lower habitat availability for pollinators, weightings were based on available academic literature. Using the maps produced by Casalegno et al. (2014) shows that the coastal corridor has a slightly higher mean score of habitat availability for pollinators than the rest of Cornwall, with a 5% lower amount of habitat with 'low' potential to provide pollinator habitats and a 5% greater amount of habitat with medium potential to provide pollinator habitats.

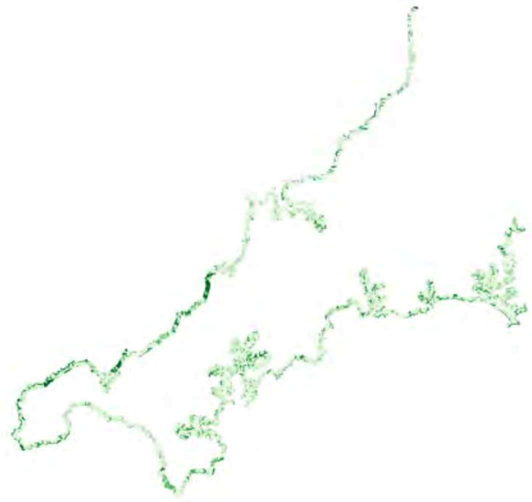
Using the maps of the distribution of habitat availability for pollinators shows high concentration around the NW coast of Cornwall, particularly surrounding West Penwith, Godrevy and Holywell (Casalegno et al. 2014). Notably, looking at the Cornwall wide distribution of habitats for pollinators shows that the most suitable habitats are potentially around the Bodmin Moor area, near Pendeen and Zennor, in the Penwith district and near Gwendreath in the Lizard area.

Habitat availability for pollinators	Coastal Corridor	Cornwall
Mean (Score for all habitat)	16.8	15.46
Standard deviation	15.02	15.32
Low	69%	74%
Medium	22%	17%
High	8%	7%
Very High	1%	2%

Table 90. Habitat with potential to provide pollinator habitat (Source: Casalegno et al. 2014)



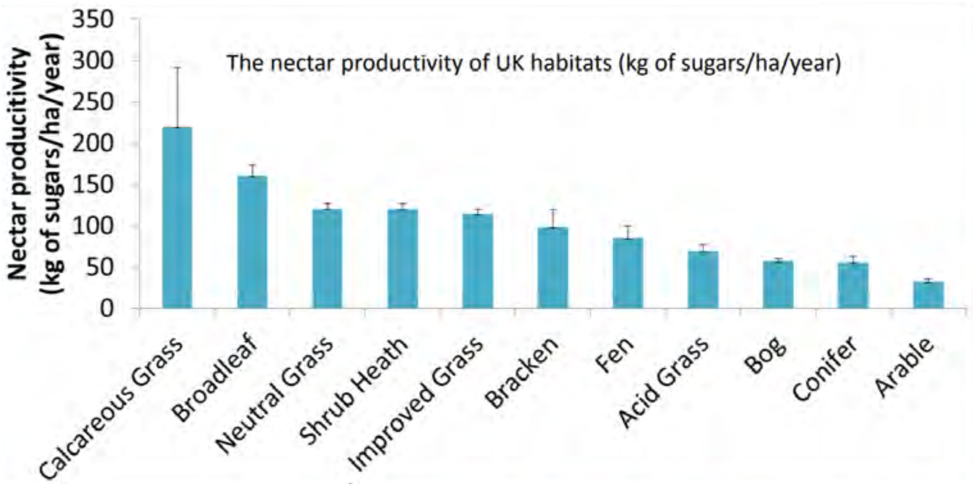
Map 21. Habitat availability for pollinators (100m resolution) (Darker colours equal higher availability) (Source: Casalegno et al 2014)



Map 22. Habitat availability for pollinators (100m resolution) (Darker colours equal higher availability) (Source: Casalegno et al 2014)

Nectar Productivity

Lack of food, nectar and pollen, is believed to be one of the major causes of pollinator decline in the UK (Baude et al. 2016; Hicks et al. 2016[200]). To calculate nectar productivity variation nationally, Baude et al. (2016) estimated the nectar productivity per flower and then scaled up their findings to estimate the nectar productivity of different vegetation units and then broad habitat types (kg of sugars/ha/year)[201]. They found that certain habitats, e.g. calcareous grasslands, broadleaved woodlands and neutral grasslands, produce much higher levels of nectar productivity (and diversity) than others, such as arable (Graph 9).



Graph 9. Nectar productivity of UK habitats (kg of sugars/ha/year) (Source: Baude et al. 2016; Memmott 2016[202])

Using the estimates of mean nectar productivity per ha (kg of sugars/ha/year) summed by the area of different habitat types suggests that habitats in the coastal corridor have the capacity to produce around 3.94 million kg of sugars per year, with a mean nectar productivity of 77.2 kg per ha. The largest total contributors are improved grassland, broadleaf woodland, and shrub heath. Calcareous grassland has the highest mean nectar productivity per ha per year. Baude et al. (2016) advise that calcareous grassland should be a priority habitat for conservation dedicated to pollinators. Within the coastal corridor, calcareous grassland is concentrated around one site at Holywell with high potential to be of importance to be enhanced to encourage greater nectar provision.

---

[200] Hicks et al. (2016) Food for pollinators: quantifying the nectar and pollen resources of urban flower meadows. PLoS ONE 11(6): e0158117. https://doi.org/10.1371/journal.pone.0158117
[201] Baude et al. (2016) https://www.nature.com/articles/nature16532
[202] Memmott (2016) https://www.agriland.leeds.ac.uk/news/documents/4_JaneMemmottnectarresources.pdf

Habitat	Mean Nectar productivity (kg of sugar per ha per year)	Coastal Corridor		Rest of Cornwall		Cornwall	
		Area (ha)	Nectar productivity (kg of sugar per year)	Area (ha)	Nectar productivity (kg of sugar per year)	Area (ha)	Nectar productivity (kg of sugar per year)
Acid grassland	65	12.6	819	10465.7	680270.5	10478.3	681089.5
Arable	25	25055.6	626,390	73564.3	1839107.5	98619.9	2465497.5
Bog	50	0	0	376.6	18830	376.6	18830
Broadleaf	160	6954.2	1,112,672	23101.8	3696288	30056	4808960
Calcareous Grass	220	93.8	20,636	21.4	4708	115.2	25344
Conifer	50	165.5	8275	4445.8	222290	4611.3	230565
Fen	80	27.2	2176	45.8	3664	73	5840
Improved Grassland	115	16321.2	1,876,938	153084.9	17604763.5	169406.1	19481701.5
Neutral Grass	120	47.3	5676	42.7	5124	90	10800
Shrub Heath	120	2432	291,840	7883.9	946068	10315.9	1237908
Estimated Total Nectar produced by above habitats (kg of sugar per year)			3,945,422		25,021,113		28,966,536
Mean nectar productivity kg/ha			77.2		91.6		89.4

Table 91. Nectar productivity in the coastal corridor (kg of sugars per ha per year), (Source: Baude et al 2016; Memmott 2016)

Biological diversity

- *The coastal corridor is a significant reserve of some of our most protected sites for biodiversity and contains 74 Sites of Special Scientific Interest (SSSI), which cover some 8.2% of the area of the coastal corridor [5927 ha] and 29.4% of the total area of designated SSSI in Cornwall.*
- *Approximately, 13,566 ha of the Cornwall Coastal Corridor is covered by UK BAP priority habitats, 21% of the total area of the corridor. In comparison, BAP habitats cover only 14% of the total area of Cornwall. Despite equating to only 18% of the area of Cornwall the coastal corridor contains 27% of the total BAP habitat area in Cornwall.*
- *The coastal corridor is particularly important for the following priority habitats: saltmarsh (82% of total area in Cornwall): sand dunes (85%), maritime cliffs and slopes (98%), reedbeds (91%), saline lagoons (90%), good quality semi-improved grassland habitats (69%), lowland calcareous grassland habitat (78%), lowland dry acid grassland (59%), lowland meadows habitat (45%), and traditional orchard habitat (37%).*

Decades of research have shown that biodiversity plays a vital role in ecosystem functioning and that processes such as capturing essential resources, producing biomass and recycling nutrients, are all impaired as biodiversity declines. A growing body of research also shows that biodiversity plays a significant role in underpinning and supporting the stable provision of multiple ecosystem goods and services. The exact relationship between biodiversity and each individual ecosystem service varies and there are ongoing debates as to whether biodiversity should be understood as an ecosystem service itself (e.g. Mace et al., 2012[203]) or is the underlying concept providing ES.

The coastal corridor is a significant reserve of some of our most protected sites for biodiversity and contains 74 Sites of Special Scientific Interest (SSSI), which cover some 8.2% of the area of the coastal corridor [5927 ha] and 29.4% of the total area of designated SSSI in Cornwall. UK BAP priority habitats are those semi-natural habitats identified as being the most threatened and requiring conservation action under the UK Biodiversity Action Plan (UK BAP). In essence, priority habitats are a focus for conservation action in England. There are 65 BAP habitats on the UK BAP priority habitats list under Section 41 of the Natural Environment and Communities Act (2006). Priority habitats can be designated SSSI, they also fall outside SSSI and can occur with stewardship agreement, or fall outside the protection of all schemes. Approximately, 13,566 ha of the Cornwall Coastal Corridor is covered by UK BAP priority habitats, 21% of the total area of the corridor. In comparison, BAP habitats cover only 14% of the total area of Cornwall. Despite equating to only 18% of the area of the Cornwall the coastal corridor contains 27% of the total BAP habitat area in Cornwall.

The coastal corridor is particularly important for the following priority habitats: saltmarsh (82% of total area in Cornwall): sand dunes (85%), maritime cliffs and slopes (98%), reedbeds (91%), saline lagoons (90%), good quality semi-improved grassland habitats (69%), lowland calcareous grassland habitat (78%), lowland dry acid grassland (59%), lowland meadows habitat (45%), and traditional orchard habitat (37%). Looking at this in terms of the SW regional scale, the coastal corridor contains 11% of the SW coastal salt marsh, 39% of the region's coastal sand dunes, and 42% of the region's maritime cliffs and slopes. In terms of

[203] *Mace et al. (2012) Biodiversity and ecosystem services: A multilayered relationship. Trends in Ecology and Evolution. 27 (1): 19-25.*

percentage area of the coastal corridor, the major BAP habitats include deciduous woodland (33%), maritime cliffs and slopes (30.8%) and lowland heathland (10%), coastal sand dunes (7.9%), good quality semi-improved grassland (5.3%). BAP priority habitats are relatively evenly distributed, occurring throughout the coastal corridor, apart from the major urban conurbations. Very little of the coastal corridor is without any BAP habitats. Map 23 shows a heatmap of the clusters of BAP priority habitats which shows strong clustering around: Lyther River Estuary, River Tamar Upper Estuary, River Fal Estuary, Lizard Point, Treen, St Ives Bay, and Perranporth.

Main Habitat	Coastal Corridor		Cornwall		SW		CC as % of total in Cornwall
	Ha	% of total	Ha	% of total	Ha	% of total	
Blanket bog	0	0.0%	477	1.0%	19203	4.4%	
Calaminarian grassland	2	0.0%	94	0.2%	94	0.0%	2%
Coastal and floodplain grazing marsh	91	0.7%	454	0.9%	70175	16.2%	20%
Coastal Saltmarsh	281	2.1%	343	0.7%	2452	0.6%	82%
Coastal sand dunes	1065	7.9%	1254	2.5%	2718	0.6%	85%
Coastal vegetated shingle	0	0.0%	0	0.0%	350	0.1%	
Deciduous Woodland	4550	33.5%	21103	42.1%	149466	34.5%	22%
Fragmented heath	0	0.0%	483	1.0%	1511	0.3%	
Good quality semi-improved grassland	721	5.3%	1053	2.1%	14099	3.3%	69%
Grass moorland	17	0.1%	3456	6.9%	17556	4.1%	
Lowland calcareous grassland	105	0.8%	135	0.3%	35969	8.3%	78%
Lowland dry acid grassland	29	0.2%	49	0.1%	2404	0.6%	59%
Lowland Fen	116	0.9%	637	1.3%	3913	0.9%	18%
Lowland heathland	1353	10.0%	7009	14.0%	18934	4.4%	19%
Lowland meadows	35	0.3%	76	0.2%	7336	1.7%	45%
Lowland raised bog	0	0.0%	0	0.0%	354	0.1%	
Maritime cliff and slope	4181	30.8%	4249	8.5%	9957	2.3%	98%
Mud flats	77	0.6%	1952	3.9%	11855	2.7%	4%
Purple moor grass and rush pasture	14	0.1%	621	1.2%	5927	1.4%	2%
Reed-beds	23	0.2%	25	0.0%	313	0.1%	91%
Saline lagoons	35	0.3%	39	0.1%	417	0.1%	90%
Traditional orchard	87	0.6%	235	0.5%	5330	1.2%	37%
Upland flushes, fens and swamps	0	0.0%	287	0.6%	1217	0.3%	
Upland hay meadow	0	0.0%	14	0.0%	31	0.0%	
Upland heathland	0	0.0%	3171	6.3%	25815	6.0%	
Upland calcareous grassland	0	0.0%		0.0%	3	0.0%	
No main habitat, but additional habitats present	781.99	5.8%	2931	5.8%	25914	6.0%	

Table 92. UK BAP habitats in the coastal corridor

Map 23. Heat map of BAP priority habitats within the coastal corridor.

4.02.04 Cultural Ecosystem Services

Recreation

- *Greenspaces, paths and beaches (see footnotes for full list[204]) within the coastal corridor are predicted to receive approximately 18.64 million recreational day visits by English adult residents per year, with an associated annual welfare benefit to residents of £74 million (Day and Smith 2018[205]).*
- *If this is extended to include the 500m area immediately surrounding the Coastal Corridor it rises to 26.26 million predicted greenspace visits, with an associated welfare benefit to residents £110 million (*isbd).*
- *The coastal corridor alone accounts for 49% of the total predicted recreational visits by adults to greenspace in Cornwall, and 51% of the total welfare benefit to residents in Cornwall (*isbd).*
- *The coastal corridor extended by 500m accounts for 70% of the total predicted recreational day visits by adults to greenspaces, and 76% of the total welfare benefit to residents provided by greenspace visits across Cornwall (*isbd).*
- *Visits to the SWCP in Cornwall account for 41.7% of the predicted visits to the entire network of the SWCP per year across the SW (day trips by resident English adults only) (*isbd).*
- *Filtering the results of the OrVAL model (Day and Smith 2018) to explore only the value of coastal sites (including visits to beach, coastal, saltmarsh, seaside or estuary) suggest that these coastal habitats alone receive 11.26 million recreational visits per year with a derived total welfare value of £61,0404,352 per year (*isbd).*
- *Looking at the breakdown between the broad habitat types shows that within the corridor the proportions of visits are relatively evenly split between beaches, parks and paths. Once extended by 500m 43% of visits are to beaches compared to 24% to parks and 33% to paths.*

The recreation importance of green spaces in the coastal corridor has been estimated using the ORVal model (Day and Smith 2018). The ORVal[206] model is a statistical recreational demand model which can be used to predict the likely number of visits to existing green spaces and the associated welfare values of those visits in monetary terms (See technical report[207]) (Day and Smith 2018). ORVal is based on an econometric model of recreation demand using data from the Monitor of Engagement with the Natural Environment (MENE) Survey (Natural England, 2010). It is important to emphasise that the value and visits predicted by ORVal represent only a broad estimate of the likely current benefits (Day and Smith 2018), and provides only an indication of the value that can be preserved or achieved.

The model estimates a '*welfare value'* for greenspace visits which describes the monetary equivalent of the welfare enjoyed by an individual as a result of having access to green space, or in this case access to sites within the Coastal Corridor (Day and Smith, 2018). Welfare refers to the sense of well-being or utility that an individual feels from their experiences (Day and Smith 2018). Welfare value is predicted based on the extra welfare enjoyed by adult residents from the beneficial attributes of a green space, and therefore how much each individual's welfare would fall if they were no longer able to access that site. Monetary values are calculated using travel-cost methods by examining how many trips individuals living at different distances, and hence with different travel costs, choose to make to a recreational green space. The valuation approach is based on the assumption that the value individuals derive from that visit is worth at least the costs incurred in travelling to the site (time and travel costs). ORVal predicts visits from a person-level choice model, or discrete choice model, which tries to predict how likely it is that an adult (over 16) with particular characteristics living in a particular location will choose to visit a particular green space from a set of green spaces available. The model is based on data reported in the MENE and tries to take into account the following factors (1) the size, qualities and characteristics of a green space (i.e land covers), (2) the proximity and socio-economic composition of nearby populations, (3) the availability of alternative sites, and (4) the day of the week/year.

The fundamental assumption of the model is that the choice to visit different greenspaces is somehow '*welfare maximising'* (Day and Smith 2018), i.e. this assumes that the welfare of visiting a greenspace exceeds the welfare of doing something different. Furthermore, the values and visitor number generated by ORVAL are based on the assumption that accessible green space is in

---

[204] ORVal Includes country parks, amenity parks, recreation grounds, village greens, golf courses, gardens, woods, amenity woods, allotments, cemeteries, grave yards.
[205] Day and Smith (2018) Outdoor Recreation Valuation (ORVal) User Guide: Version 2.0, Land, Environment, Economics and Policy (LEEP) Institute, Business School, University of Exeter.

[206] Day, and Smith (2018) Outdoor Recreation Valuation (ORVal) User Guide: Version 2.0, Land, Environment, Economics and Policy (LEEP) Institute, Business School, University of Exeter.
[207] ORVAL technical report: : https://www.leep.exeter.ac.uk/orval/documents

average condition for its type (Day and Smith 2018). The model is also restricted by the parameters of the MENE survey which only collects data on recreational day trips, for residents of England and adults (over 16). For full details on the ORVal model and methodology please refer to the full technical report[208] or Day and Smith (2018). While the ORVal model can provide insight into the number, welfare value and distribution of visits across Cornwall's Coastal Corridor, it does not tell us anything about their activities in these green spaces.

	Cornwall Coastal Corridor		Cornwall Coastal Corridor+ 500 m		Cornwall	
	Visits	Value	Visits	Value	Visits	Value
Beaches & Harbours	5,504,863	£ 29,909,536	11,264,354	£ 61,040,352	37,716,818	£ 145,205,131
Parks	5,782,970	£ 19,514,383	6,417,171	£ 21,541,461		
Paths	7,348,461	£ 24,578,279	8,582,353	£ 28,302,325		
Total	18,636,295	£ 74,002,198	26,263,878	£ 110,884,138	37,716,818	£ 145,205,131
	% CUA total	% CUA total	% CUA total	% CUA total		
	49%	51%	70%	76%		
Beaches	30%	40%	43%	55%		
Parks	31%	26%	24%	19%		
Paths	39%	33%	33%	26%		

Table 93. Recreational visits and value for the coastal corridor (Day and Smith 2018)

Tranquillity

- *The coastal corridor has a lower than average relative tranquillity score compared to the rest of Cornwall.*
- *Large areas of the north coastline contain long unbroken stretches of relatively high tranquillity. Notably, the NE section of the coast and around the west of the Lizard peninsular contain some of the largest stretches of high tranquillity in the coastal corridor.*

Tranquillity is a widely used term that is generally taken to refer to a state of calm, peace and quietude associated with wellbeing (Jackson et al. 2008[209]). Feeling tranquil is thought to induce feelings of calm and is thought to be linked with positive effects on health and quality of life for individuals (Jackson et al. 2008). Psychological research has repeatedly highlighted that being in tranquil places allows people to relax, escape stress and '*recharge their batteries*'. Therefore, tranquillity is also a perceptual quality of the landscape. A tranquil area is described by Jackson et al. (2008:4) as an "*area with the characteristics most likely to induce a state of tranquillity for people who are there*". There is, however, also an appreciation that in our modern world the ability to access areas which promote tranquillity is getting harder (Jackson et al. 2008).

The capacity of an area to promote tranquillity is a significant asset, and one which often appears in local policy (e.g. Cornwall Environmental Growth Strategy 2015). Many factors are thought to contribute to an individual's feeling of tranquillity, which is thought to be promoted visual, aural and to a lesser extent other sensory stimuli either as a direct response or a cue to memory (Jackson et al. 2008). Attempting to map tranquillity is by no means an easy exercise, but can help to provide an indication of the places where people are more likely to feel tranquil, and potentially, therefore, areas which needed to be valued and protected.

In 2008, CPRE mapped tranquillity nationally (Jackson 2008) to provide an estimated value of the relative tranquillity for individual 500m^2 grid squares for the whole of England in 2006. The CPRE tranquillity map was produced based on scoring areas of land in relation to 44 positive and negative factors, generated through participatory approaches. In essence, the CPRE scores an area against positive tranquillity factors (e.g. view of nature, openness, naturalness) and negative factors that are thought to detract from the tranquillity of an area (e.g. aeroplane noise, population density, noise levels). The resulting CPRE (2008) tranquillity map shows a spectrum of more or less tranquil area, determined by the combination of positive and negative scores for each grid square. In essence, the map shows areas that have more or fewer important characteristics thought to be associated with tranquillity, and therefore are more or less likely to provide users with the space and conditions to relax, achieve mental balance and a sense of distance from stress.

---

[208] *ORVAL technical report: : https://www.leep.exeter.ac.uk/orval/documents*
[209] *Jackson et al.. (2008) Tranquillity Mapping: developing a robust methodology for planning support, Report to the Campaign to Protect Rural England, Centre for Environmental & Spatial Analysis, Northumbria University, Bluespace environments and the University of Newcastle upon on Tyne. - file:///C:/Users/rm653/Downloads/tranquillity_mapping_developing_a_robust_methodology_for_planning_support%20(1).pdf*

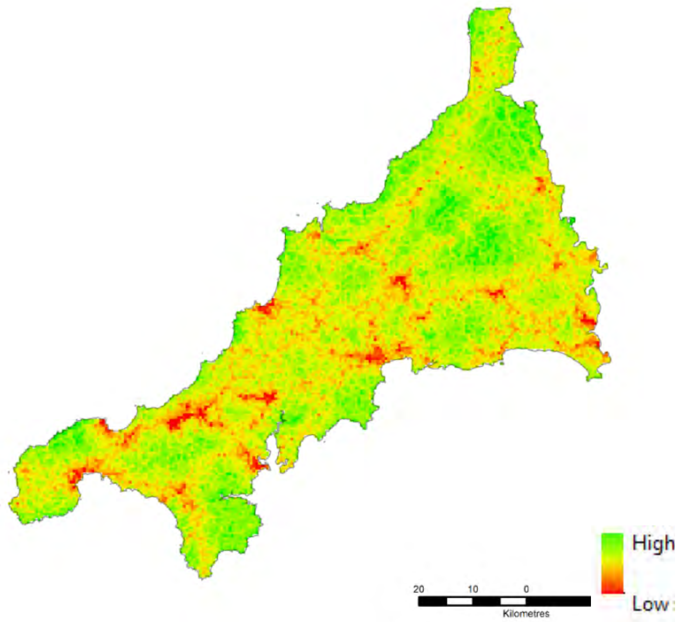
To estimate tranquillity in the coastal corridor, the CPRE tranquillity map was replotted to show the relative tranquillity scores across Cornwall to provide a basic assessment of the highest, and lowest, scoring areas the coastal corridor (Maps 24 and 25). The maps of the distribution of relative tranquillity in Cornwall show low scores along major road networks and densely populated urban areas. Large areas of the north coastline contain long unbroken stretches of relatively high tranquillity. Notably the north-east section of the coast and around the west of the lizard peninsular are some of the largest stretches of high tranquillity in the coastal corridor. However, the coastal corridor has a lower mean score for tranquillity than the rest of Cornwall with a mean value of 4.9 compared to the Cornwall mean of 5.43. The areas which score highest for tranquillity are found in the Bodmin Moor area in the central east of Cornwall. However, the coastal corridor does contain a lower minimum value for tranquillity than Cornwall as a whole. Looking at tranquillity scores by area shows that 53% of the area of the corridor has an above average score for tranquillity.

	Coastal Corridor	Cornwall	UK
MEAN	4.9	5.43	0.41
MIN	-66.6	-72.3	-140.5
MAX	52.1	130	148
ST.DEV	19.95	16.9	29.2

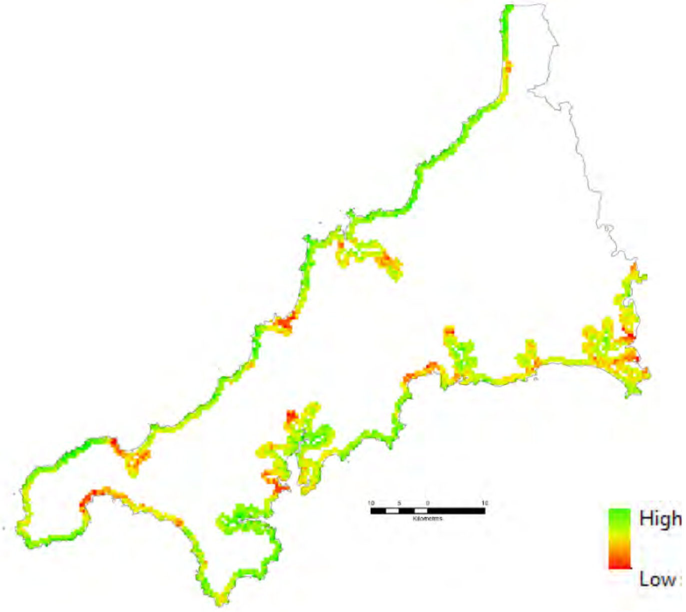
Table 94. Average tranquility scores for CUA and CC (Source: Jackson et al 2008; CPRE 2008)

Tranquillity Score Range		CC tranquillity scores by area		CUA tranquillity scores	
		Sum of area (m2)	% total area	Sum of area (m2)	% total area
Very Low	> -140.5 <-92.3	0	0%	0	0%
Low	>92.3 <-44.1	16213023	3%	39673831	1%
Med-Low	<-44.1 >4.08	287139182	44%	1679672489	47%
Medium	>4.08 to <52.7	343981221	53%	1882806450	52%
High	>52.7 <100.5	0	0%	3743523	0.1%
Very High	>100.5 <148.7	0	0%	0	0%

Table 95. Percentage area by tranquility scores (Source: Jackson et al 2008; CPRE 2008)



Map 24. Tranquillity across Cornwall (CPRE 2008)



Map 25. Tranquillity across the coastal corridor (CPRE 2008)

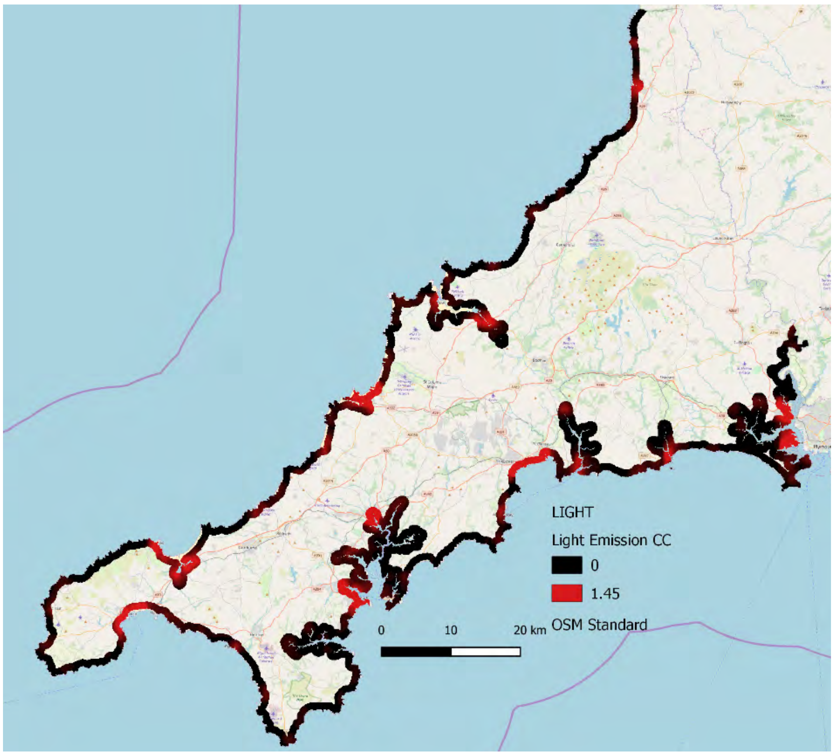
Dark Skies

"*Natural darkness is essential to a full appreciation of our surroundings, to satisfy curiosity, to appreciate our environment in all its facets, and to preserve our diverse cultural integrity*" (Dark Sky Parks 2019[210]). Among many other benefits, dark skies help to preserve the ecological integrity of natural experience, enable us to have a more '*wildness'* experience, protect the beauty of rural landscapes. Light pollution levels for the coastal corridor, including direct light emission and sky glow level, maps for Cornwall were produced by Cox et al (2019)[211]. Comparing the coastal corridor and Cornwall shows that the coastal corridor has a slightly higher mean level of both light emission and skyglow. In general, levels of high light pollution (shown in red on Map 26) correspond with urban areas, there are some notable stretches of low light pollution within the coastal corridor, including between Bude and Newquay (62km), between Truro and St Austell (44km), the Lizard and Helston and Falmouth (47km), and between Penzance and St Ives (40km). See also the Tevi Hub[212].

	Emissions		Skyglow	
	Coastal Corridor	Cornwall	Coastal Corridor	Cornwall
Maximum	1.445	1.445	0.886	0.886
Mean	0.35	0.200	0.12	0.0997
Minimum	0	0	0.011	0.010
Stddev	0.445	0.36	0.117	0.07

Table 96. Light pollution in the coastal corridor (Source: Cox et al 2019)

[210] http://darkskyparks.org/dark-skies-and-nature-conservation/
[211] Cox et al. (2019) Direct emissions from artificial light a night in Cornwall, excluding albedo and skyglow.Raster generated tiffs for Cornwall have a 0.008983153 degree resolution.
[212] https://jrmosedale.github.io/dashboard/#c-light-emissions



Map 26 Direct light emissions across the coastal corridor (Source: Cox et al. 2019).

Aesthetics

- *All 39 hotspots of highest aesthetic value, mapped by Casalegno et al. (2013[213]), are located in the coastal corridor. "Hotspots of aesthetic value (35 of 3,843 grid cells) were all located in coastal areas: seven were in coastal towns (population>3000), 17 close to sparsely populated settlements (<3000 inhabitants), and 11 in unpopulated areas (beaches or touristic coastal sites)*" (Casalegno et al 2013).
- *65% of the coastal corridor is designated for its landscape value as an Area of Outstanding Natural Beauty (AONB) (41,901 ha), which equates to 40% of the total area designated as an AONB across Cornwall.*

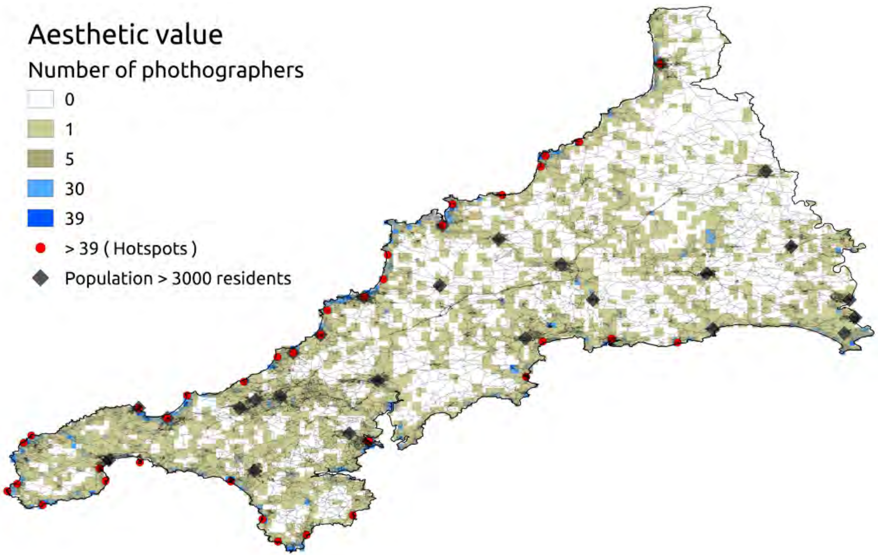
Aesthetics refers to the '*pleasure people derive from viewing or visiting the natural environment'* (Casalegno et al. 2013). Natural aesthetics have been found to correlate with higher levels of life satisfaction, and improved levels of physical and mental health. Norton et al (2012[214]) highlight that certain features of the landscape may be particularly important for the effective delivery of aesthetic services, including natural features such broadleaved woodland, water, altitude, and coasts. The Cornish coastline is renowned for the '*beauty of its natural landscape'* as well as the high-quality of its beaches. 65% of the coastal corridor is designated as an Area of Outstanding Natural Beauty (AONB) (41,901 ha), and this equates to 40% of the total area designated as an AONB in Cornwall.

Casalegno et al. (2013) quantified and mapped the perceived aesthetic value that people place on different natural capital assets across Cornwall. Casalegno et al. (2013) mapped aesthetic value using as a proxy the quantity and spatial distribution of geo-tagged digital photographs of the natural environment uploaded to the social media site Panoramio. This is based on the premise that those areas more highly valued for their aesthetic attributes will generate 'hotspots' of activity (Casalegno et al. 2013). Panoramio hosts photos of 'places of the world', with a particular focus on images of landscapes, natural features (such as woodlands) and animals in their natural environment (Casalegno et al 2013). Aesthetic value is calculated in terms of the number of individuals per unit area (1km^2) uploading photographs to Panoramio, rather than the total number of photographs uploaded in each area which reflects the level of activity of individual photographers rather than the overall value placed on a site by visitors. Casalegno et al (2013) acknowledged that this approach at capturing aesthetic value is limited and a variety of other possible approaches could have been

[213] Casalegno et al. (2013) Spatial covariance between aesthetic value & other ecosystem services. PLoS ONE 8(6): e68437. https://doi.org/10.1371/journal.pone.0068437.
[214] Norton et al. (2012) Trialling a method to quantify the cultural services of the English landscape using countryside survey data. Land Use Policy 29: 449-455.

taken, including the number of tourist attractions, tax value of summer holiday homes, number of reported sightings of rare species, tourist expenditure, accessibility to natural areas, etc (Casalegno et al. 2013).

From the 113,686 photographs mapped by Casalegno et al. (2013) (Map 27), the most highly valued areas in terms of aesthetic value were found to be concentrated around the coast. '*Hotspots of aesthetic value (35 of 3,843 grid cells; Figure 2) were all located in coastal areas: seven were in coastal towns (population>3000), 17 close to sparsely populated settlements (<3000 inhabitants), and 11 in unpopulated areas (beaches or touristic coastal sites)*' (Casalegno et al. 2013). Notably, the 39 hotspots of highest aesthetic value in Cornwall (shown on Map 27), including Kynance Cove, Port Issac, Gwithian Beach, Perranporth and Constantine Bay, were all found to be located in the coastal corridor. Casalegno et al. (2013) also found a negative correlation between population density and aesthetic value (CRH correlation=−0.56, n=55, *p-value<0,001*).



Map 27. Aesthetic value map of Cornwall (Casalegno et al. 2013).

Heritage

- *Despite representing just 17% of the land area of Cornwall, the coastal corridor was found to contain the majority, 54%, of Cornwall's Conservation Areas. More than a third of the 145 Conservation Areas are coastal towns and villages, and 40% of Cornwall's registered parks and gardens are situated directly along the south coast.*
- *The corridor also contains an estimated 15% of all scheduled monuments and 49% of listed buildings, 16% of the Cornish World Heritage Site. Heritage coast designations cover 31%, some 20,577 ha, of the coastal corridor.*

Cultural heritage has many definitions. For the purpose of this review, it is defined as the '*immediately visible and invisible tangible human-made remnants of the past*', such as archaeological sites (invisible, subsoil remains and visible, standing structures) and historic buildings (Choay and Françoise 2001[215]; Hølleland et al. 2017 [216]). In the context of ecosystem services and natural capital, cultural heritage is often referred to as the experiential quality of the landscape, sense of place or cultural landscape. For the purpose of this report, cultural heritage has been addressed only in a limited way in terms of the immediately visible human-made remnants of the past.

Cornwall Council's Historic Environment Records (Cornwall Council 2019[217]) have been used to provide a sense of the number of cultural heritage features which lie within the coastal corridor (Table 97). No attempt has been made to differentiate between heritage features which may have greater or lesser cultural importance. Despite representing just 17% of the land area of Cornwall, the coastal corridor was found to contain the majority, 54%, of Cornwall's Conservation Areas, these are areas of special architectural or

[215] *Choay. (2001) The Invention of the Historic Monument. Allégorie du patrimoine. Cambridge: Cambridge University Press.*
[216] *Hølleland et al. (2017) Cultural heritage and ecosystem services: a literature review. Conservation and Management of Archaeological Sites 19: 210-237, DOI: 10.1080/13505033.2017.1342069*
[217] *https://www.cornwall.gov.uk/environment-and-planning/strategic-historic-environment-service/cornwall-and-scilly-historic-environment-record/*

historic interest with a character or appearance that is desirable to preserve or enhance. More than a third of the 145 Conservation Areas are coastal towns and villages, and 40% of Cornwall's Registered Parks and Gardens shelter directly along the south coast. Thousands of other sites, monuments and buildings, of local importance and maritime significance, can also be found on the coast, within estuaries and along rivers. The corridor also contains an estimated 15% of all scheduled monuments and 49% of listed buildings, and 16% of the Cornish World Heritage Site. Heritage coast designation covers 31%, some 20,577 ha, of the coastal corridor.

There are thousands of recorded shipwrecks located off the coast of Cornwall, thirteen of which are nationally important and statutorily protected, including two WWI submarine war graves. Over 100 Scheduled Monuments, ranging from Bronze Age barrows to WWII gun batteries, and 2500 Listed Buildings, including well-preserved harbours, quays and fish cellars, lighthouses and coastguard stations, also dot the coastline. Marine archaeology is also important and there are over 60 known inter-tidal and inshore sites of palaeo-environmental deposits. These include the remains of ancient land surfaces and submerged forests that provide evidence of the early prehistoric environments of Cornwall and demonstrate how climate change has contributed to sea-level rise in the past.

Feature	CC		Cornwall		CC % Cornwall
	Count	Area	Count	Area	
Conservation areas	78	2159	145	4411	54% [48% by area]
Scheduled monuments	304	348	1345		15%
Listed buildings	6159		12552		49%
Cornish world heritage site		2898		18222	16%
Archaeological sites visible on aerial photographs (Neolithic to 194)	*44,944 mapped features along the coast identified through aerial photographs.				

Table 97. Heritage features within the coastal corridor (Source: Cornwall Council 2019)

Health and well-being

- *Populations living near the coast in England are healthier than those inland (Wheeler et al., 2012) and longitudinal data suggest that individuals are healthier during periods when they live closer to the coast (White et al., 2013).*
- *The link between living near the coast and good health was also found to be strongest in the most economically deprived communities, suggesting that access to the coastal environment can have a role in reducing health inequalities between wealthiest and poorest members of society (Wheeler et al 2012, White et al. 2013).*

Although difficult to quantify, recent research has shown that there is a health benefit to living near the coast. Using Census (2001) data, Wheeler et al (2012)[218] found that populations living near the coast in England have higher self-reported health levels than those inland, and furthermore longitudinal data suggest that individuals are healthier during the period when they live close to the coast (White et al. 2013[219]). The link between living near the coast and good health was also found to be strongest in the most economically deprived communities, suggesting that access to the coastal environment can have a role in reducing health inequalities between wealthiest and poorest members of society (Wheeler et al 2012, White et al. 2013). Further research has shown that one reason for higher health levels near the coast is that people living closer to the coast are more likely to undertake physical activity than inland dwellers (Wheeler et al 2014) with consequent health benefits. The coast is not only considered to offer better opportunities for physical activity but also to have significant benefits in terms of stress reduction. White et al (2014)[220] emphasise that these findings suggest that the coast is an often under-appreciated public health resource.

[218] Wheeler et al. (2012) Does living by the coast improve health and wellbeing? Health & Place 18: 1198-1201.
[219] White et al (2013) Coastal proximity, health and well-being: results from a longitudinal panel survey. Health Place 23: 97-103.
[220] White et al (2014) Coastal proximity and physical activity: Is the coast an under appreciated public health resource? Preventive Medicine 69: 135-140.

5. APPENDIX

Appendix X. Agricultural Grade Land

AGRICULTURAL LAND	*Cornwall UA*		*SW Region*	
	Area (ha)	% total area	Area (ha)	% total area
Grade 1	893.42	0.3%	34,209	1%
Grade 2	28,109.13	8.0%	178,838	8%
Grade 3	215,378.68	61.2%	1,382,721	59%
Grade 4	67,227.68	19.1%	435,472	18%
Grade 5	23,303.68	6.6%	130,571	6%
Non-Agri	11,203.96	3.2%	108,661	5%
Urban	6,115.18	1.7%	84,516	4%
TOTAL	352,231.7		2,354,989	
Average value	Average Farmland Value: £6,500 (per acre) £16,055 per ha			
All Agri Grade land	£5,376,980,050			
Grade 1 or 2	£9000 *2.7	£704,748,600		
Grade 3	£6500	£3,779,883,900		
Grade 4 or 5	£4500	£1,006,240,950		
Total value	£5,490,873,450			

Appendix X. Characteristics of Farmland Areas in Cornwall (Cornwall Council)

A	West and Central Cornwall (Killas)	Often contain larger farmers, wealthier estates. Associated with productivity, sheltered land in areas of the ancient medieval enclosure
B	The Culm North Cornwall Atlantic coast and hinterland (Bude)	Open, sparsely populated, agriculturally poor, with heavy soils. Predominantly dispersed settlement and irregular field patterns of medieval origin with few small market centres. Some higher status arable farms
C	Killas – East Cornwall	Many farms of medieval origin marked by a high predominance of livestock farming, especially moorland edge farms which benefited from proximity to Bodmin Moor. Well-preserved medieval field patterns are often tree-lined, giving the impression of greater woodland cover than is actually the case.
D	Killas – North coastal plain	Higher predominance of small scale farms dating from the 17th century and often situated on less productive exposed land subject to regular enclosure. Farms tend towards the independent farmer rather than estate owned tenanted farms, although these occur in pockets of more anciently enclosed land. Includes areas of very distinctive miners' smallholdings
E	Bodmin Moor	Exposed granite uplands dominated by moorland beef and sheep farming. Mainly isolate farms.
F	Killas – South-East Cornwall	Similar in character to the west and central Cornwall with productive, sheltered land in areas of ancient medieval enclosure, strip fields and farming hamlets, but with proportionally higher numbers of relatively large farms, particularly arable based. Many of the farms are linked to just 4 or 5 dominant estates; classic Cornish Barton landscape
G	Henbarrow	Exposed granite upland landscape of dynamic change dominated by the china clay industry. Dispersed farmstead and hamlets. Relatively low levels of investment, especially in areas under threat of expanding mineral extraction.
H	Carnmenellis	Small, roughly circular granite upland. Significant ancient metalliferous production. Predominately isolate farmsteads mixed with small-nucleated mining/quarrying settlements Little inward investment since decay of the mining industry, much amalgamation of farms and re-use of agricultural buildings.
I	West Penwith	Cornwall's only major coastal granite upland. Sparsely populated; mining and fishing as dominant as agriculture in history and settlement. Heavy emphasis on pastoral farming, with extensive rough ground grazing, limited mixed arable in the fertile southern area (St Buryan) and sheltered valleys. From 19th century horticulture developed in coastal areas and Mount's Bay fringes. On the edges of the peninsula are a number of small fishing or mining villages/towns, otherwise predominantly hamlets with dispersed layouts, especially associated with town-places – one of the most distinctive aspects of the area, as are many small-scale miner-farmer linear smallholdings around St Just.
J	Lizard and Meneage	Gently undulating exposed heathland plateau cut by sheltered river valleys; complex geology. Historical distinction in landownership, land quality and use between the Lizard (south and west of the area) and the richer Meneage (north and east). Good mixed farming/grain lands set amongst extensive areas of rough grazing. Significant evidence of ancient farming and settlement in a hamlet-based settlement pattern, interspersed with occasional rural market, fishing and quarrying centres. Early farmsteads typically linear or dispersed (although noticeably less 'townplace' farmsteads than e.g. west Penwith).

Table X. Character of different farmland areas across Cornwall (Source: Cornwall Council XXXX)

Appendix. X Breweries across Cornwall in relation to the coastal corridor

Brewery	Address	Approximate Distance to MHW
Ales of Scilly	2B Porthmellon Industrial Estate, St Mary's, Isles of Scilly TR21 0JY	0.12km
All Saints	Unit 10B, Cardrew Industrial Estate, Redruth, Cornwall TR15 1SS	4.57km
Atlantic Brewery and Distillery	Treisaac Farm,Treisaac, Newquay, Cornwall TR8 4DX	3.47km
Black Flag Brewery	Unit 4D, Bridge Road Industrial Estate, Goonhavern, Cornwall TR4 9QL	3.25km
Black Rock Brewing	Unit 6C, Empire Way, Falmouth TR11 4SN	1.51km
Blue Anchor Brewery	50 Coinagehall St, Helston TR13 8EL	3.39km
Bude Brewery	Kings Hill Industrial Estate, Bude, Cornwall EX23 8QN	1.901
Castle Brewery (micro)	Unit 9A, Restormel Industrial Estate, Liddocoat Road, Lostwithiel, Cornwall PL222 0HG	5.43km
Coastal Brewery	Unit 20, Cardrew Trade Park South, Cardrew Way,	4.50km
Cornish Chough	Trethvas Farm, The Lizard, Cornwall Tr12 7AR	0.826km
Cornish Crown	1 Victoria Square, Penzance, Cornwall TR18 2EP	0.270km
Cornish Crown Brewery	Cornish Crown Brewery, Badgers Cross, Penzance TR20 8XE	2.157km
Driftwood Spars Brewery	Trevaunance Cove, St Agnes, Cornwall TR5 0RT	0.189km
Dynamite Valley Brewing Co	Viaduct Works, Frog Hill, Ponsanooth, Cornwall TR3 7JW	5.383km
Firebrand Brewing (Altarnum Brewing Limited	Inner Trenarrett, Altarnun, Cornwall PL15 7SY	16km
Fishkey Brewing Co(micro)	Unit 4, Granite Quay, Looe, Cornwall PL13 1DX	0.162km
Forge brewing	Wilderland Herb Fam, Woolley, Bude, Cornwall	1.48km
Fowey Brewery	Unit 3F, Restormel Industrial Estate, Liddicoat Road, Loswithiel, Cornwall PL22 0HG	7.3km
Harbour Brewing Co. Ltd	Trekillick, Kirland, Cornwall PL30 5BB	11.1km
Keltek Brewery	Candela House, Cardrew Way, Redruth, Cornwall TR15 1SS	4.56
Lizard Ales	Coverack, Helston TR12 6SE	0.963km
Longhill Brewery	Longhill Cottage, Whitstone, Holsworthy, Cornwall EX22 6UG	7.8km
Padstow Brewing Company	The Brewery, Padstow, Cornwall PL28 8RW	1.49km
Penpont Brewery	Inner Trenarrett, Altarnun, Launceston, Cornwall PL15 7SY	16.41
Penzance Brewing Co	Star Inn, Crowlas, near Penzance, Cornwall TR20 8DX	2.143km
Rebel Brewing Co	Century House, Parhengue Road, Kernick Industrial Estate, Penryn, Cornwall TR10 9EP	1.77km
Sharp's Brewery	Rock, Cornwall PL27 6NU	1.778km
Skinners Brewery	Riverside, Newham Road, Truro TR1 2DP	0.577km
St Austell Brewery	63 Trevarthian Road, St Austell, Cornwall PL25 4BY	2.584km
St Ives Brewery (StIvesCider)	Trewidden Road, St Ives, Cornwall TR26 2BX	0.298km
Tintagel Brewery	Condolden Farm, Tintagel, Cornwall PL34 OHJ	3.461km
Verdant Brewing Co	Unit 6, Tresidder Close, Tregoniggie Industrial Estate, Falmouth, Cornwall TR11 4SP	1.22km
Wooden Hand Brewery	Unit 3, Grampound Road Industrial Estate, Near Truro, Cornwall TR2 4TB	9.81km

References

Alonso et al. (2012) Carbon storage by habitat: Review of the evidence of the impact of management decisions and condition of carbon stores and sources. Natural England Research Reports.Natural England. Sheffield.

Andrews et al. (2006) Biogeochemical value of managed realignment, Humber estuary, UK. Science of The Total Environment, 371, 19-30

Angus et al. (2011) Coastal Margins. In: The UK National Ecosystem Assessment Technical Report. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge. Available at: http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=dNI5e5W5I5Q%3D&tabid=82

Baude et al (2016) https://www.nature.com/articles/nature16532;

Beaumont et al. (2014) The value of carbon sequestration and storage in coastal habitats. Estuarine, Coastal and Shelf Science, 137. 32-40. https://doi.org/10.1016/j.ecss.2013.11.022

Berglund et al. (1999) Guidelines for community noise. World Health Organization https://apps.who.int/iris/handle/10665/66217

Bignal et al. (2004) The ecological effects of diffuse air pollution from road transport. English Nature Research Report 580.

Bolund and Hunhammar (1999) Ecosystem services in urban area. Ecological Economics, 29, 293-301.

Borrelli et al. (2017) A New Assessment of Soil Loss Due to Wind Erosion in European Agricultural Soils Using a Quantitative Spatially Distributed Modelling Approach. Land Degradation & Development, 28: 335–344, DOI: 10.1002/ldr.2

Braunman et al. (2007) The nature and value of ecosystem services: an overview highlighting hydrologic services. Annu Rev Environ Resour, 32: 67–98.[Crossref], [Web of Science ®], , [Google Scholar]

Breeze et al. (2011) Pollination services in the UK: How important are honeybees? Agriculture Ecosystems and Environment, 142 (3), 137-143, Available at: https://www.researchgate.net/publication/251520349_Pollination_services_in_the_UK_How_important_are_honeybees

Broadmeadow and Matthews (2003) Forest, carbon and climate change: the UK contribution. Forestry Commission Information Note 48.

Buckman and Southern (2015) Empployment and Skills Strategy, CIOSLEP, Available atL https://www.cioslep.com/assets/uploads/documents/1469447094_Employment%20and%20Skills%20Strategy%20(new%20version).pdf

Bullock et al. (2011) Semi-Natural Grasslands, In the UK NEA (2011), Available at: http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=lfVaZJDoV8c%3D&tabid=82

Burkhard et al. (2012) Mapping ecosystem service supply, demand and budgets. Ecological Indicators 21, 17–29

Casalegno et al. (2013) Spatial Covariance between Aesthetic Value and Other Ecosystem Services, PLOS ONE, 8(6). https://doi.org/10.1371/journal.pone.0068437

Casalegno et al. (2014) Regional Scale Prioritisation for Key Ecosystem Services, Renewable Energy Production and Urban Development. PLoS ONE 9(9): e107822. https://doi.org/10.1371/journal.pone.0107822

CEH (2014) Pollinator map, Available at: https://eip.ceh.ac.uk/naturalengland-ncmaps/reports/pollinators.pdf

CEH (2015) Land Cover Map 2015, Available at: https://www.ceh.ac.uk/services/land-cover-map-2015 Contains Ordnance Survey data © Crown copyright and database right [year]

CEH (2015) Nectar plant diversity for bees, https://eip.ceh.ac.uk/naturalengland-ncmaps/reports/pollinators.pdf; Maskell, L.;

CEH (2017) Land Cover Map Plus Crops 2017

Choay and Françoise (2001) The Invention of the Historic Monument. Allégorie du patrimoine. Cambridge: Cambridge University Press.

Christie et al. (2010) Economic Valuation of the Benefits of Ecosystem Services delivered by the UK Biodiversity Action Plan, Defra Project: NE0112, Final report. Available at: http://users.aber.ac.uk/mec/Publications/Reports/Value%20UK%20BAP%20FINAL%20published%20report%20v2.pdf

CLOS Futures Group (2017) A catalyst for change, Available at: https://www.cornwall.gov.uk/media/24227365/catalyst-for-change-brexit-report.pdf

Coffee et al. (2013) Relatively residential property value as a socio-economic status indicator for health research, Int J Health Geography 12:22, 10.1186/1476-072X-12-22

Cornwall and Isles of Scilly Leadership Board (2018) Post-Brexit Framework: New Frontiers, Available at: https://www.cornwall.gov.uk/media/35807050/new-frontiers-2018_part_2.pdf

Cornwall Annual Population Survey (2016) employment in Tourism;

Cornwall Council (2011) 2011 Census at a glance, Webpage, Available at: https://www.cornwall.gov.uk/media/3624040/Census_at_a_glance_1stRelease.pdf

Cornwall Council (2011) Tourism Issues Paper, Core Strategy Evidence Papers, Cornwall Council Planning Department, https://www.cornwall.gov.uk/media/3639137/Tourism.pdf

Cornwall Council (2012) A future for maritime Cornwall: The Cornwall Maritime Strategy 2012-2030, Annex: background information, https://www.cornwall.gov.uk/media/3623049/Annex-background-information-2-.pdf

Cornwall Council (2012) Agriculture and food issues paper, Available at:: https://www.cornwall.gov.uk/media/3638076/Agriculture-and-Food.pdf

Cornwall Council (2012) Cornwall Farmstead Character Statement, Available at: https://www.cornwall.gov.uk/media/28925561/cornwall-farmsteads-character-statement2_red.pdf

Cornwall Council (2012) Economy and Culture Strategy Evidence Base, Available at: https://www.cornwall.gov.uk/media/3624007/Economy-and-Culture-Strategy-Evidence-Base.pdf

Cornwall Council (2013) Population and Population projections, Cornwall Local Plan: Housing Evidence Base Available at: https://www.cornwall.gov.uk/media/3642933/BN3-Population-v3-Nov-13.pdf

Cornwall Council (2014) Local Population Projectton Pyramids, Webpage, Available at: https://www.cornwall.gov.uk/media/22243248/2014-based-local-population-projections_pyramids.pdf

Cornwall Council (2015) Environmental Growth Strategy.

Cornwall Council (2016) State of the Economy, Available at:: https://www.cornwall.gov.uk/media/17635607/state-of-the-economy-jan16.pdf

Cornwall Council (2017) Cornwall Site Allocations, Available at: https://www.cornwall.gov.uk/media/21956015/dpd-whole-document-v2.pdf; https://www.cornwall.gov.uk/environment-and-planning/planning/planning-policy/examinations-201718/cornwall-site-allocations-dpd/cornwall-site-allocations-dpd-examination-position-statements/

Cornwall Council (2017) Population, Webpage, Available at: https://www.cornwall.gov.uk/council-and-democracy/data-and-research/data-by-topic/population/

Cornwall Council (2018) 2018 Air Quality Annual Status

Cornwall Council (2018) Defra Consultation on a Post Brexit Domestic Farming Policy (DFP) which is entitled “Health and Harmony: the future for food, farming and the environment in a Green Brexit” https://www.cornwall.gov.uk/media/35785823/defra-consultation-final-submitted-response-4th-may-2018.pdf

Cornwall Council (2018) Population Projections, Webpage page, Available at: https://www.cornwall.gov.uk/health-and-social-care/public-health-cornwall/joint-strategic-needs-assessment-jsna/data-maps-and-infographics/tab-placeholder-hidden/data/population-projections/

Cornwall Council and CIOS Futures Group (2017) https://www.cornwall.gov.uk/media/30280220/cornwall-council-and-cios-fg_brexit-and-local-government-inquiry-3-2.pdf

Cornwall Council Historic Environment Record, Available at:[1] https://www.cornwall.gov.uk/environment-and-planning/strategic-historic-environment-service/cornwall-and-scilly-historic-environment-record/

Cornwall Futures Group (2017) A Catalyst for Change – Implications, Risk and Opportunities of Brexit for Cornwall and the Isles of Scilly, CIoS Futures Group, January 2017 https://www.cornwall.gov.uk/media/24227365/catalyst-for-change-brexit-report.pdf

CROME Crop Map of England (2017) https://data.gov.uk/dataset/e2f5de8d-a46e-4c8b-800d-3375cf19ad57/crop-map-of-england-crome-2017-north

Cumulus Consultants Ltd and ICF GHK (2013) Valuing Englands National Parks, Available at: https://www.nationalparksengland.org.uk/__data/assets/pdf_file/0004/717637/Valuing-Englands-National-Parks-Final-Report-10-5-13.pdf

Cumulus Consulting (2017) The potential impacts of Brexit on the SW Coast land the implications for future agricultural policy, Internal report for the National Trust, unpublished.

Dales et al. (2014) Assessing the potential for mapping ecosystem services in England based on existing habitats. Natural England Research Reports, Number 056

Day and Smith (2018) Outdoor Recreation Valuation (ORVal) User Guide: Version 2.0, Land, Environment, Economics and Policy (LEEP) Institute, Business School, University of Exeter.

Defra (2017) State of Agriculture in the UK, Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/741062/AUK-2017-18sep18.pdf

Defra (2018) Defra June Agricultural Survey, Available at: https://www.gov.uk/agricultural-survey; https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june

Defra (2018) The Future Farming and Environment Evidence Compendium, Online Report, Available at; https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/683972/future-farming-environment-evidence.pdf

Duchy College (2016) Farm Business Digest - Farm Business Survey https://www.ruralbusinessschool.org.uk/the-farm-business-survey/

EA (2011) Water for life and livelihoods: River basin management plan SW River Basis District, EA report, Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/292791/gesw0910bstp-e-e.pdf

EA (2019) Evidence Directory - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/654440/Working_with_natural_processes_one_page_summaries.pdf

EA (2019) Source Protection Zones, Available at:https://data.gov.uk/dataset/09889a48-0439-4bbe-8f2a-87bba26fbbf5/source-protection-zones-merged

Eftec (2015) Developing UK Natural Capital Accounts: Woodland Ecosystem Accounts, Report to Defra, Available at: http://sciencesearch.defra.gov.uk/Document.aspx?Document=12480_DevelopingUKNCAccounts_WoodlandEcosystemAccount_FINAL_March2015.pdf

ERCCIS (2009) Land cover report, Available at: https://www.google.com/search?q=ERCCIS+2009+land+cover+change&oq=ERCCIS+2009+land+cover+change&aqs=chrome..69i57.2973j0j4&sourceid=chrome&ie=UTF-8

Falchi et al. (2016) The new world atlas of artificial night sky brightness. Science Advances 2(6): e1600377.

Fang and Ling (2003) Investigation of the noise reduction provided by tree belts. Landscape and Urban Planning 63:187–195

FBS (2019) Farm Business Survey, Available at: http://www.farmbusinesssurvey.co.uk/

Forestry Commission (FC) (2017) National Forest Inventory Statistics for Devon, Cornwall and the Isles of Scilly: https://www.forestresearch.gov.uk/documents/3000/FR_NFI_statistics_report_DCS_2017.pdf

Forest Research (2017) National Forest Inventory, Available at: https://www.forestresearch.gov.uk/tools-and-resources/national-forest-inventory/about-the-nfi/

Forest Research (2019) National Forest Inventory, Available at: https://www.forestresearch.gov.uk/tools-and-resources/national-forest-inventory/

GeoIndex Onshore (2019) http://mapapps2.bgs.ac.uk/geoindex/home.html?layer=BGSMinAM

Health Protection Agency (2010) Health protection legislation guidance 2010, Available at: https://webarchive.nationalarchives.gov.uk/20100716121707/http://www.hpa.org.uk/web/HPAwebFile/HPAweb_C/1246433634856

Henrys et al. (2016) Bee nectar plant diversity of Great Britain. NERC Environmental Information Data Centre. http://doi.org/10.5285/623a38dd66e8-42e2-b49f-65a15d63beb5

Hicks et al. (2016) Food for pollinators: quantifying the nectar and pollen resources of urban flower meadows. PLoS ONE 11(6): e0158117. https://doi.org/10.1371/journal.pone.0158117

HM Land Registry (2019) Price Paid Dataset: https://www.gov.uk/government/statistical-data-sets/price-paid-data-downloads

Hølleland et al. (2017) Cultural Heritage and Ecosystem Services: A Literature Review, Conservation and Management of Archaeological Sites, 19:3, 210-237,DOI: 10.1080/13505033.2017.1342069

Hölzinger and Laughlin (2016) Cornwall Area of Outstanding Natural Beauty Natural Capital Assessment, Main Report, The Cornwall AONB Unit, Truro, Available at: https://static1.squarespace.com/static/54e6ffe7e4b0663b4a777e12/t/5892fb04725e25be04c61e3d/1486027528048/CAONB+NCA+Main+Report+Final+Feb+2017.pdf

Jackson et al. (2008). Tranquillity Mapping: developing a robust methodology for planning support, Report to the Campaign to Protect Rural England, Centre for Environmental & Spatial Analysis, Northumbria University, Bluespace environments and the University of Newcastle upon on Tyne. - file:///C:/Users/rm653/Downloads/tranquillity_mapping_developing_a_robust_methodology_for_planning_support%20(1).pdf

Jones et al. (2008) Factors controlling soil development in sand dunes: evidence from a coastal dune soil chronosequence. Plant Soil, 307,219– 234

Jones et al. (2019) Natural capital accounting and air quality removal; Available at: https://www.charteredforesters.org/wp-content/uploads/2019/01/Jones-et-al-Natural-capital-accounting-of-the-air-quality-regulating-....pdf

Klein et al. (2006) Importance of pollinators in changing landscapes for world Crops, Proceedings of the royal society B, Biological sciences, 274, 1608. Available at: https://royalsocietypublishing.org/doi/full/10.1098/rspb.2006.3721

Knight Frank (2018) Knight Frank Farmland Index, Available at: https://content.knightfrank.com/research/157/documents/en/english-farmland-index-q1-2019-6317.pdf;

LandIS (2019) NATMAP CARBON: Soil Organic Carbon Map, Available At: http://www.landis.org.uk/data/nmcarbon.cfm

Lautenbach et al (2012) https://www.tandfonline.com/doi/full/10.1080/21513732.2011.631940

Lobley et al. (2011) A review of Cornwall's Agri-Food Industry: Final report, CRPR Research Report No 32, Available at: https://socialsciences.exeter.ac.uk/media/universityofexeter/research/microsites/centreforruralpolicyresearch/pdfs/researchreports/Cornish_food_economy_final_report_FINAL.pdf

Loomis (2000) Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. Ecol Econ, 33(1): 103–117

Mace et al. (2012) Biodiversity and ecosystem services: A multilayered relationship. Trends in Ecology and Evolution. 27 (1), pp. 19–25.

Mace et al. (2015) REVIEW: Towards a risk register for natural capital, Journal of Applied Ecology

Maltby andAcreman (2011) Ecosystem services of wetlands: pathfinder for a new paradigm. Hydrological Sciences Journal, 56 (8), 1341-1359.

Maskell et al. (2016) Bee nectar plant diversity of Great Britain. NERC Environmental Information Data Centre. http://doi.org/10.5285/623a38dd66e8-42e2-b49f-65a15d63beb5

Memmott (2016) https://www.agriland.leeds.ac.uk/news/documents/4_JaneMemmottnectarresources.pdf

Mosedale et al (2019 in press) https://jrmosedale.github.io/dashboard/#c-light-emissions

Natural Capital Committee (2014) NCC State of natural capital second report, Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/516698/ncc-state-natural-capital-second-report.pdf;

Natural Capital Committee (2015) How to do it: a natural capital workbook, Version 1, Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/608852/ncc-natural-capital-workbook.pdf

Natural Capital Committee (2019) NCC Annual report 2019, Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/774218/ncc-annual-report-2019.pdf

Natural England (2008) State of Nature, Available at: http://publications.naturalengland.org.uk/publication/31043

Natural England (2015)Nectar plant diversity for bees, https://eip.ceh.ac.uk/naturalengland-ncmaps/reports/pollinators.pdf;

Natural England (2019) Provisional agricultural land classification, Available at: https://data.gov.uk/dataset/952421ec-da63-4569-817d-4d6399df40a1/provisional-agricultural-land-classification-alc

Natural England (2019) Sites of Special Scientific Interest Units (England) Attribution statement: © Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right [year]. Attribution statement: Attribution statement: © Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right [year] https://data.gov.uk/dataset/c52ead19-47c2-473b-b087-0842157e00b6/sites-of-special-scientific-interest-units-england

NEA (2011) Coastal Margins, Available at: http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=dNI5e5W5I5Q%3D&tabid=82

Nisbet et al. (2011) Woodland for Water: Woodland measures for meeting Water Framework Directive objectives. Forest Research Monograph, 4, Forest Research, Surrey, 156pp.

Nomis (2015) UK Enterprise Counts, Available at:[1] http://www.sqw.co.uk/files/2313/8531/4708/Strat_5.pdf

Norton et al. (2012) Trialling a method to quantify the cultural services of the English landscape using countryside survey data. Land Use Policy 29: 449–455.

ONS (2011) Census: Digitised Boundary Data (England and Wales) [computer file]. UK Data Service Census Support. Downloaded from: https://borders.ukdataservice.ac.uk/. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3].

ONS (2011) Census geography, Webpage, Available at: https://www.ons.gov.uk/methodology/geography/ukgeographies/censusgeography

ONS (2011) Census: Digitised Boundary Data (England and Wales) [computer file]. UK Data Service Census Support. Downloaded from: https://borders.ukdataservice.ac.uk/. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3]

ONS (2011) Occupation, Available at: https://www.nomisweb.co.uk/census/2011/qs606uk

ONS (2011) Rural-urban classification, Web page, Available at: https://www.ons.gov.uk/methodology/geography/geographicalproducts/ruralurbanclassifications/2011ruralurbanclassification

ONS (2013) General Health and wellbeing and the 2011 Census, Available at https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/healthandwellbeing/articles/generalhealthinenglandandwales/2013-01-30

ONS (2013) ONS Regional Tourism Ratios https://www.ons.gov.uk/peoplepopulationandcommunity/leisureandtourism/articles/theregionalvalueoftourismintheuk/2013

ONS (2015) Buisness register and Employment survey: Workers by Industry Employed in, ONS.

ONS (2015) Employment and Labour Market Profile, Available at: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/articles/transitionfromamanufacturingtoserviceledlabourmarketoverpast170years/2015-08-06

ONS (2015) English Indices of Deprivation, Available at: https://www.gov.uk/government/statistics/english-indices-of-deprivation-2015;

ONS (2017) Regional GVA by Local Authority, Available at: https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/regionalgvaibylocalauthorityintheuk

ONS (2018) UK Natural Capital Accounts: Developing Semi-Natural Grasslands, Available at: https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/uknaturalcapitaldevelopingseminaturalgrasslandecosystemaccounts

ONS (2018) UK Business Counts - Inter Departmental Business Register, Available at: https://www.nomisweb.co.uk/reports/lmp/la/1946157349/report.aspx?#tabidbr

ONS Population projections, Webpage, Available at::https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections

ONS; National Records of Scotland ; Northern Ireland Statistics and Research Agency (2016): 2011 Census data. UK Data Service (Edition: June 2016). DOI: http://dx.doi.org/10.5257/census/aggregate-2011-1. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3].

Ordance Survey (OS) (2017) English County Longest Coastline, Webpage, Available at: https://www.ordnancesurvey.co.uk/blog/2017/01/english-county-longest-coastline/

Painting et al. (2010) Defra report MEC3205. Results of fieldwork to quantify key process affecting the flow of C, N, O and Si at key sites in the North Sea. 65.

Panagos et al. (2015) The new assessment of soil loss by water erosion in Europe. Environmental Science & Policy. 54: 438-447. DOI: 10.1016/j.envsci.2015.08.012

Pope (2017) GB Postcode Area, Sector, District, [Dataset]. University of Edinburgh. https://doi.org/10.7488/ds/1947. Contains Ordnance Survey data © Crown copyright and database right 2012 Contains Royal Mail data © Royal Mail copyright and database right 2012 Contains National Statistics data © Crown copyright and database right 2012. GIS vector data

Quine and Walling (1991) Rates of soil erosion on arable fields in Britain: quantitative data from caesium-137 measurements, Soil Use and Management, 7 (4), 169-176, https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1475-2743.1991.tb00870.x

Read et al. (eds) (2009) Combating climate change – a role for UK forests. An assessment of the potential of the UK‟s trees and woodlands to mitigate and adapt to climate change. The Stationery Office, Edinburgh.

Redman (2018) John Nix Pocketbook for farm management 2019, 49th Edition, Agro-Business Consultants, Melton Mowbray.

Reis et al. (2017) UK gridded population 2011 based on Census 2011 and Land Cover Map 2015. NERC Environmental Information Data Centre. https://doi.org/10.5285/0995e94d-6d42-40c1-8ed4-5090d82471e1https://catalogue.ceh.ac.uk/documents/0995e94d-6d42-40c1-8ed4-5090d82471e1

Report (ASR), Available at: https://www.cornwall.gov.uk/media/35432115/cornwall-council-asr_2018-final.pdf

RSPB Farmland Bird Indicator: https://www.rspb.org.uk/our-work/conservation/conservation-and-sustainability/farming/near-you/farmland-bird-indicator/

S4W (2017) Economic and Social Impacts of EEA Area Workers in Cornwall and the Isles of Scilly, Research Report, Cornwall Council and the Cornwall and Isles of Scilly Local Enterprise Partnership Cornwall Council, https://www.cioslep.com/assets/file/Economic%20and%20Social%20Impacts%20of%20EEA%20Area%20Workers%20on%20Cornwall%20and%20the%20Isle.pdf

Savills (2018) Farmland Market Report 2018, Available at: https://www.savills.co.uk/research_articles/229130/274008-0.

Sing et al. (2015) https://www.forestry.gov.uk/PDF/FCRN020.pdf/$FILE/FCRN020.pdf

Smith et al. (2011). Regulating services. In: The UK National Ecosystem Assessment Technical Report. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge.

South West Coast Path (2015) Year 5 analysis summary, Available at: https://www.southwestcoastpath.org.uk/media/uploads/swcp_year_5_analysis_summary_-_key_findings.pdf

SWRC (2016) SW Coast Path Monitoring and Evaluation Framework, Year 5 (2015) Key Findings, Produced on behalf of the SW Coast Path Team.

SWRC (2018) Cornwall Visitor Survey 2018/19 Quarterly update, Produced on behalf of Visit Cornwall.

SWRC and Visit Cornwall (2018) The economic impact of Cornwall's Visitor Economy 2017;

Tennessen et al. (2014) Traffic noise causes physiological stress and impairs breeding migration behaviour in frogs. Conserv Physiol. doi: 10.1093/conphys/cou032

UK National Ecosystem Assessment Follow-on (2014) The UK National Ecosystem Assessment Follow-on: Synthesis of the Key Findings. UNEP-WCMC, LWEC

Van der Wal et al. (2011) Mountains, Moorlands and Heaths. UK National Ecosystem Assessment. The UK National Ecosystem Assessment Technical Report. UNEP-WCMN, Cambridge, pp. 105–159.

Visit Cornwall (2017) Value of Tourism in Cornwall 2017, The SW Research Company.

Visit Cornwall and Cornwall Council (2014) Cornwall's Visitor Economy Strategy 2014-2020, Consultation Document, https://www.visitcornwall.com/sites/default/files/generic_files/Cornwall%20Visitor%20Economy%202014-20%20Consultation.pdf

Wheeler et al (2012) Does living by the coat improve health and wellbeing? Health Place, 18(5). 1198-1201. oi: 10.1016/j.healthplace.2012.06.015

White et al (2013). Coastal proximity, health and well-being: results from a longitudinal panel survey. Health Place; 23:97-103

White et al. (2014) Coastal proximity and physical activity: Is the coast an under-appreciated public health resource? Preventive medicine, 69,135-140. https://doi.org/10.1016/j.ypmed.2014.09.016

White et al (2015) Ecosystem accounts for protected areas in England and Scotland: technical appendix, report to Defra, Available at: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19271

Whittaker (2017) Cornwall's Vital Issues 2017, Cornwall Community Foundation, Available at: http://www.ukcommunityfoundations.org/wp-content/uploads/2017/10/Cornwalls-Vital-Issues-2017.pdf

Whittaker (2017) Cornwall's Vital Issues 2017 Report, Available at: https://www.cornwallcommunityfoundation.com/wp-content/uploads/2018/12/Cornwalls-Vital-Issues-2017-Final-2.pdf

Winn, et al (2015) EcoServ-GIS Version 3.3 (Great Britain): A toolkit for mapping ecosystem services. User Guide. The Wildlife Trusts.

WWF (2019) Water Risk Filter, Available at: http://waterriskfilter.panda.org/en/Explore/Map

SWEEP Tool information

Enhancing access to the NEVO Tool - Natural Environment Valuation Online

The NEVO Tool (https://www.leep.exeter.ac.uk/nevo/) is a powerful, open-access, web application designed for regional spatial planning. It can be used to explore the integrated relationships between climate change, land-use change, ecosystem service flows and economic values. SWEEP is helping to improve its accessibility and function. Click here for a short Demo Video.

Who are NEVO users?

- Land-owners and managers
- Councils, Local Authorities
- Government organisations
- National Parks, AONBs
- Charities, Trusts
- Private sector organisations
- Academic, students

How does it work?

NEVO allows users to explore, quantify and make predictions about the environmental costs and benefits arising from changes in land-use across England and Wales.

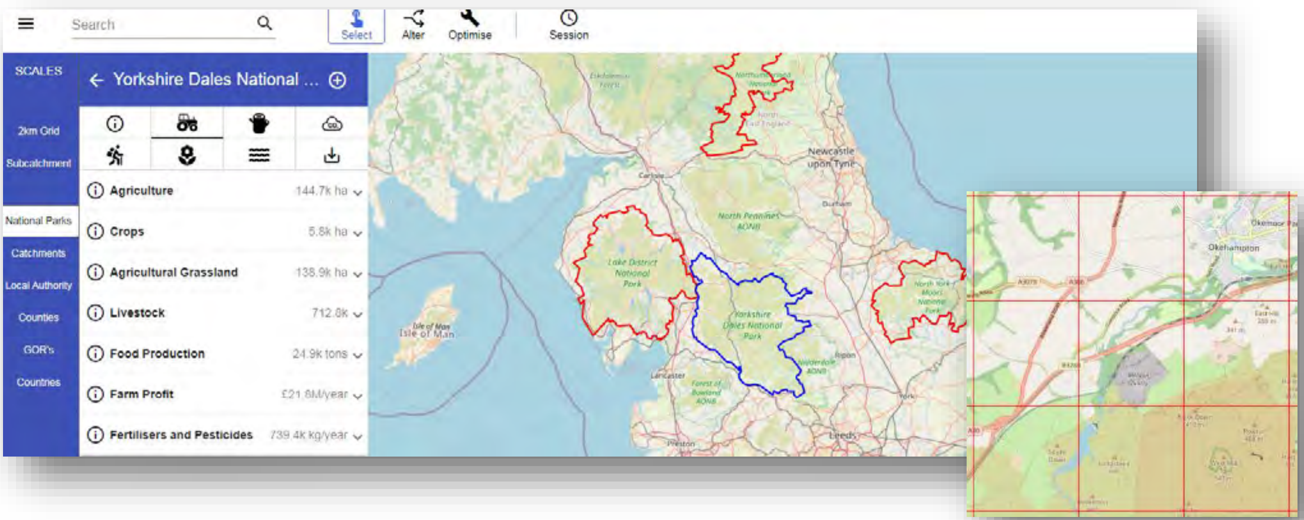
It brings together spatially explicit data, natural science and economic models and allows users to view baseline and predicted information at different spatial scales for a **range of ecosystem services** including:

- Agricultural production
- Woodlands and timber production
- Greenhouse gas emissions
- Recreation
- Biodiversity
- Water quantity and quality.

What can it do?

NEVO can be used to explore the current situation and then move beyond this, to consider 'alternative' and 'optimal' scenarios based on a range of criteria.

- **Establishing baseline information**
  Mapping and data downloads can be exported to support regional spatial planning and ecosystem analysis projects.
- **Exploring alternative land use scenarios**
  Ask *what if?* questions to explore how changes in land-use and pricing could affect landscapes and pr actice.
- **Optimising land-use to support policy development**
  Ask *what's best?* questions to optimise landscapes for examining and evaluating regional land use policy development.



Scale and functionality

The NEVO Tool can explore land use at various scales, including **administrative scales**, e.g. local authorities and government office regions (GORs), **terrain-based scales**, such as **river network sub-basins** and up to country scale (England and Wales). NEVO is designed with analytical units based on a 2 km grid covering the entirety of England and Wales. It is not intended to support decision-making at an individual farm or 2 km plot scale. Its strength lies in allowing users to compare land use change at a broader scale.

The tool contains three types of functionality: Explore, Alter and Optimise.

Explore ecosystem services derived from land use in selected areas

The 'Select' panel contains summary information about land use in the defined area for the decade 2020-2030. A scroll bar allows users to move through time to see how land use and ecosystem services are predicted to change through time, taking into account climate change (using mid-range projections from UKCP09). Outputs can be downloaded as CSV files or maps.

Alter landscape characteristics

The 'Alter' mode allows users to consider 'what if?' questions. Once users have selected an area (by clicking on it in the map), they are able to consider how the flow of ecosystem services would change over time if they were to alter the land use or agricultural prices in the area.

Optimise land use

The 'Optimise' mode in NEVO allows users to consider 'what's best?' questions relating to finding the best locations to change land use in order to achieve a particular objective. Users can specify the type of land use change (from what, to what), the total amount of hectares to be changed, and the overall objective, which can be to maximise particular quantity outputs (e.g. biodiversity richness) or value outputs (e.g. timber and agricultural profits).

NEVO's development

NEVO was launched in 2019 and developed by the Land, Environment, Economics and Policy Institute (LEEP, University of Exeter), with support from DEFRA and NERC.

Its **accessibility and scope** are being extended through the NERC-funded South West Partnership for Environment & Economic Prosperity (SWEEP) with new features including:

- Welcome Tour
  Interactive walk through
- Video Tutorials
  Video demonstration of how to use the tool
- Case Studies and Technical Documentation
  More information about the NEVO models
- CSV Variables Names
  Downloads an Excel Spreadsheet with variable descriptions

If you have ideas for further improving NEVO's functionality and user experience, please contact us

The NEV models

The NEVO Tool is an online version of the **Natural Environment Valuation (NEV) suite of models** - a ground-breaking spatially-explicit, integrated modelling platform which quantify and values the cascading effects of land use change through ecological and economic systems.

NEV links drivers of change including policy, market forces and the environment to impacts on food production, carbon sequestration, water quality, flood mitigation, biodiversity and numerous other ecosystem services.

For details of the NEV modelling suite, please see:

Day D, Owen N, Binner A, et al (2020). The Natural Environmental Valuation (NEV) Modelling Suite: A Summary Technical Report. LEEP Working Paper.

Contact: Brett.Day@exeter.ac.uk

Underpinning NERC science

The NEVO team, led by Dr. Amy Binner and Prof. Brett Day have worked on numerous NERC funded projects including the Valuing Nature Network, assessing ecosystem services of energy provision, payments for ecosystem services, Addressing Valuation of Energy and Nature Together (ADVENT) and the Valuing Nature Tipping Points project.

About SWEEP

The South West Partnership for Environment & Economic Prosperity (SWEEP) is a partnership between the University of Exeter, the University of Plymouth and Plymouth Marine Laboratory. Funded by the Natural Environment Research Council, SWEEP brings experts and stakeholders together to solve key challenges faced by those working with our natural resources.

Water Quality and Aquaculture
REPORT

Acid herbicide wash-off exploration tool

Guidance document

Dr James Webber, SWEEP, Impact Fellow
Dr Ross Brown, SWEEP, Impact Fellow
Dr Nick Paling, Westcountry Rivers Trust, Head of Evidence

Acid herbicide wash-off exploration tool.

Guidance document

Summary

This guidance document describes the **Acid herbicide wash-off catchment exploration tool** and details how it can be used. The tool allows users to evaluate the scale and trajectory of mobilised acid herbicides (i.e. agricultural run-off from grassland) during periods of intense rainfall and understand the potential impact on phytoplankton. It has been developed to explore these issues within the UK's South West estuaries, however the approach could be easily adapted to incorporate new catchments, chemicals and future scenarios. The tool is not intended to be a comprehensive hydrological and chemical fate model and its underpinning strengths and limitations are set out in this guidance document accordingly.

This tool and guidance document were developed under the NERC-funded South West Partnership for Environmental and Economic Prosperity programme (**SWEEP**) as part of the project on **Water Quality and Aquaculture** which seeks to evaluate the effect of water quality on the viability of bivalve aquaculture in South West England's estuaries.

Key findings

1. We have developed a simple logic chain risk assessment tool designed to evaluate relative risk from acid herbicides washing off agricultural land due to intense rainfall.
2. The approach is easily adaptable to incorporate new catchments, chemicals and future scenarios. Full explanation on how to achieve this is built into the risk assessment spreadsheet.
3. The **main utility of the tool is as a simple, high-level analysis, engagement and exploration tool**. It is intended as an initial strategic level approach, applied by an expert with understanding of its limitations, as such we have designed our tool to be easily adaptable for future adjustment and application.
4. We emphasise that this report and associated spreadsheet tool are only suitable as a high level and relative risk assessments. The approach is not calibrated or validated to provide reliable absolute values for pesticide concentrations.

For more information and details of the spreadsheet tool, please contact Dr Ross Brown (Ross.Brown@exeter.ac.uk).

Introduction

Why evaluate acid herbicides?

The toxicity of acid herbicides in the aquatic environment is generally considered to be low; however, the ubiquity of potential sources within South West England's river catchments, where such a large proportion of the total catchment area is managed grassland (which are commonly treated using acid herbicides), warrants a risk assessment of simultaneous and widespread pollution incidents triggering acute toxicity events within estuaries.

Of pertinence to the SWEEP South West England Aquaculture Study is the possibility that these events could negatively impact the phytoplankton food sources supporting bivalve populations, hindering growth or leaving shellfish susceptible to disease.

Report structure

We evaluate the acid herbicide risk assessment through examining a series of questions relating to the likelihood and magnitude of pollutant sources, pathways and receptor impacts.

- What are the key acid herbicides applied to the catchments?
- What are key transmission pathways?
- Can contaminant reach estuary?
- How much contaminant is applied?
- How much contaminant is mobile?
- How much contaminant washes off?
- What concentration could the contaminant reach in estuary?
- What is impact on phytoplankton?
- How can future scenarios be included within the tool?

What are the key acid herbicides applied to the catchments?

The predominant active ingredients in acid herbicides applied to manage grassland include 2,4-D, Clopyralid, Fluroxypyr, MCPA, Mecoprop and Triclopyr. Applications exist in a wide range of formulations for both agricultural and domestic treatments. These acid herbicides are generally soluble, highly mobile, and persistent following application, resulting in a potential risk of treatments causing damage to the aquatic environment.

	2,4-D	Clopyralid	Fluroxypyr	MCPA	Mecoprop	Triclopyr
Water-sediment DT50 (days)	18.2	-	34.7	17	141	29.2
Water phase only DT50 (days)	7.7	148	10.5	13.5	92	24.8
Adsorption (K_f)	0.7	0.071	1.2	0.94	1.54	-
Application mobile in water (%)	59%	93%	45%	52%	39%	-
Adsorption (K_{foc})	39.3	5	68	74	59.8	-
Algae acute 72-hour EC_{50}, growth (mg l^{-1}) in freshwater[1]	24.2	30.5	49.8	79.8	16.2	181

Table 1: Characteristics of predominant acid herbicides used within South West England (data from the University of Hertfordshire and IUPAC PPDB).

What are key transmission pathways?

The mobility and persistence of acid herbicides results in a risk of treatments entering watercourses and being transported into estuaries. The two main sources of contamination are agricultural and domestic application.

Agricultural application

Agricultural application of acid herbicides is typically undertaken to manage broad leaf weeds on managed grassland within two crop spraying windows: late spring and late autumn. Each field is typically treated once every four years, meaning it is reasonable to assume 25% of managed grassland will be sprayed annually.

[1] We have used the acute freshwater EC_{50} as a relative measure of toxicity due to data availability, but assess impact using the acute saltwater values, which are typically lower.

Agricultural pathways include:

- Rainfall events mobilising and washing off water-phase contaminants in field runoff following application and transporting sediment-phase contaminants into watercourse through soil erosion.
- Groundwater flow transporting water-phase contaminants to watercourses.
- Spray drift directly depositing application to field drains or watercourses.
- Poor preparation and washdown procedures leading to chemical losses from steadings to watercourses.
- Dumping or poor storage practices.

The most significant potential pathway leading to transmission of acid herbicides is a wash-off generating rainfall event triggering catchment scale contribution of recently applied chemicals. Smaller and more gradual inputs are likely to be related to leaching of eroded topsoil and groundwater flow; however, this is unlikely to reach the scale and magnitude of a widespread contamination event.

The smaller scale, improbability of simultaneous inputs, dispersed spatial application and need to deviate from well-established standard practices means that this study assumes compliant standard practice from landowners within catchments, therefore discounting risks associated with poor or negligent chemical handling and treatment. Although significant at a local scale, this type of malpractice is also less likely to be significant at a catchment scale, relative to the sort of simultaneous catchment scale input triggered by a rainfall event mobilising runoff to watercourses.

Domestic application

Domestic scale application of acid herbicides in lawn enhancing products is also a potential pathway, predominantly through CSO spills or wastewater treatment deficiencies; However, the scale of domestic gardens is substantially smaller than the total area utilised for agricultural grassland, and as such is deemed to be a less significant risk factor.

Therefore, assuming compliant best practice, we propose that the most significant acid herbicide source and transmission pathway within South West England is a high magnitude catchment scale agricultural contamination event, caused by intense rainfall triggering field wash-off.

Can contaminant reach estuary?

The first stage in our risk assessment determines whether the pathway is sufficient for contaminants to reach the receptor (estuary).

We determine that it is very likely any contaminant applied which washes off fields into watercourses will reach the estuary. This is based on the persistence of the acid herbicides, of which the minimum DT_{50} in the water phase is 7.7 days (2,4-D). This is significantly higher than the hydraulic response time of the catchments, which is in the order of hours.

Any acid herbicides existing in the aqueous phase within surface soil which then wash-off from land are likely to the reach estuaries. This could occur if a wash-off triggering rainfall event occurs in the catchment whilst acid herbicides are available.

How much contaminant is applied?

Dosage of acid herbicides varies across the range of available products; however, is typically within the magnitude of 1 – 2 kg ha^{-1}. We calculate the total amount of contaminant by multiplying the dosage (1.5 kg ha^{-1}) by area treated (ha).

Area treated varies year on year, however a typical managed grassland is treated with acid herbicides to manage broadleaf weeds on average once every four years. Spraying takes place in treatment windows in Spring and Autumn, which last approximately eight weeks.

For analysis, we have assumed 25% of total grassland is treated every year, and application is uniformly applied across two spraying windows.

How much contaminant is mobile?

We assume mobile contaminants are those which exist within the aqueous phase in surface soil. This is governed by two coefficients, the ratio between the contaminant bound to soil: mobile in a water phase (K_f) and the proportion which is washed off.

The K_f coefficient describes a default ratio of a chemical which is bound to soil versus that available in a water phase. We have converted this to a percentage of application remaining available in a water phase to calculate the total mobile contaminant.

In practice, K_f is variable based on the organic carbon available within soils. For a baseline scenario we have applied the default K_f value from the Pesticide Properties Database (Table 1), however for later stages of the risk assessment we also consider how contaminant availability varies along with soil carbon using the K_{foc} coefficient (Table 1).

How much contaminant washes off?

The wash off coefficient describes the proportion of the contaminant which is washed off during intense rainfall. This variable is highly dependent on the topography (particularly slope), soil type and structure, distance to watercourse and presence of interventions such as buffer strips. For strategic analysis, we applied a wash off coefficient of around 10% as a high-level estimate for our baseline scenario, based on the FOCUS soil report[2] which details a range of European case studies.

The proportion of contaminant which is washed off represents a small amount relative to the overall application, however we stress that this is under compliant best practice across a large area and the wash off from specific fields within watersheds is likely to vary significantly from the 10% assumed wash off. For comparison, 100% wash off, albeit very improbable, would contribute up to the total mobile

[2] FOCUS Surface Water Modelling Working Group. 2012. Generic guidance for FOCUS surface water scenarios. Section 2.3.2

contaminant. This does not take into account sediment bound particulates, which we assume remain in field, however significant wash off events may also mobilise sediment.

What concentration could the contaminant reach in estuary?

To calculate contaminant concentration in the estuary, we divide the total washed off contaminant by the estuary volume at low water. This calculation assumes the relatively worst-case assumptions of the full available washed off load entering the estuary at the same time and the estuary being at low volume when this happens. However, this also assumes a uniform contaminant distribution across the entire estuary volume which in practice is likely to be governed by complex mixing. **Error! Reference source not found.** presents the resultant concentration given these assumptions.

What is impact on phytoplankton?

We evaluate the impact on phytoplankton through examining the estuary concentration relative to two key ecotoxicity thresholds, the predicted no effect concentration (PNEC) which is used as the current Environmental Quality Standard (EQS) and the EC_{50} for the saltwater micro-algal species, *Skeletonoma costatum.*

QA versus spot samples

We have undertaken a quality assurance of our approach through comparing indicative levels with spot samples taken across the Exe Catchment. During this analysis we find that our peak concentrations are in the same order of magnitude to peaks identified within the River Exe (0 - 10 µg l^{-1}); however, we caution several significant limitations with this process:

Input conditions (application rate, extent and runoff) associated with peak monitored values are unknown, so we cannot replicate these within our risk assessment. In fact, it is unlikely that the sort of worst-case application of a uniform acid herbicide immediately prior to a rainfall event would be replicated in practice.

Monitored data are from the River Exe, where dilution is much lower than we assume in the estuary.

Monitored data points are spot samples. Recent research cautions relying on spot samples for peak values due to inability to confirm whether these capture peaks, finding a 30-fold difference between spot samples and continuously monitored peak concentrations[3].

In summary, we determine that our logic chain risk assessment can provide indicative and relative values for high level comparison but cannot validate results and so do not recommend that absolute values are considered accurate.

[3] Lefrancq *et al*. 2017. High frequency monitoring of pesticides in runoff water to improve understanding of their transport and environmental impacts. *Science of The Total Environment*
587–588, p. 75-86

To maximise this utility to stakeholders we have implemented our analysis within a risk assessment tool within which variables can easily be adapted to suit future application and iteration of analysis.

Including future scenario within the risk assessment

Due to uncertainties described in the high-level risk assessment, we consider the main utility of this analysis to be in relative comparison of scenarios, as opposed to absolute quantification of acid herbicide levels. Therefore, our risk assessment tool is easily adaptable across a range of scenarios to evaluate the relative scale and direction of change which may occur in response to catchment intervention and future conditions.

Soil management change

Managing condition is crucial to ensure soils remain effective for environmental capital and regulation. Soil condition can be considered as a function of soil health, structure and compaction.

The organic carbon content within soils is frequently used as a proxy for health, with higher organic carbon being indicative of a healthier, more resilient and more productive soil. The organic carbon within soil is also a key controlling factor in determining the ratio of acid herbicides which bind to soil relative to acid herbicides which exist in water. This relationship is defined through the constant K_{foc}, which describes the relationship between organic carbon and the soils K_f ratio.

We have included the effect of increasing soil heath by modifying K_f based on a range of soil organic carbon levels, with a low (0.5%) and a high (5%) organic carbon scenario.

Soil condition is also affected by structure and compaction. With better managed soils demonstrating a looser structure with less compaction. We have represented this within the risk assessment through adjusting the wash off variable, with a low (5%) and a high (25%) scenario.

Different soil types, land slopes and the presence of interventions such as buffer strips can also be represented by adjusting the organic carbon and wash off variables within our risk assessment spreadsheet.

Land use change

We represent land use changes through adjusting the crop types and area treated. For this analysis we have considered increasing and decreasing the treated area by 25% and 50% as an indicative representation of how future land use change within catchments may affect resultant pollutant loads.

Further detail could be added to land use change by simultaneously adapting soil condition variables, as described above.

Behaviour change

Farmer behaviour change can be represented through adjusting the application schedule and quantity. The application schedule includes changing fields treated per year, number of treatment windows and fields treated before rainfall event (a proxy of treatment window length and treatment distribution). Application quantity can be adjusted through changing the dosage rate variable.

For this analysis we evaluate changes to treatment windows and dosage rate (1 kg ha^{-1} and 2 kg ha^{-1}).

Climate change

The predominant impact of climate change on the hydrological cycle is likely to be an increase in the intensity of rainfall events. We have represented this here through adjusting the wash off variable to represent a larger rainfall event triggering high runoff rates and washing off a higher proportion of mobile contaminant. This is a difficult relationship to define, so for an indicative example we have evaluated the impact of a 50% wash off rate.

Conclusions

1. We have developed a simple logic chain risk assessment tool designed to evaluate relative risk from acid herbicides washing off agricultural land due to intense rainfall.
2. The approach is easily adaptable to incorporate new catchments, chemicals and future scenarios. Full explanation on how to achieve this is built into the risk assessment spreadsheet.
3. The **main utility of the tool is as a simple, high-level analysis, engagement and exploration tool**. It is intended as an initial strategic level approach, applied by an expert with understanding of its limitations, as such we have designed our tool to be easily adaptable for future adjustment and application.
4. We emphasise that this report and associated spreadsheet tool are only suitable as a high level and relative risk assessments. The approach is not calibrated or validated to provide reliable absolute values for pesticide concentrations.

sweep Water Quality & Aquaculture REPORT

Wholescape Assessment of Water Quality Status, drivers and impacts in the Exe Estuary Catchment and implications for ecosystem health and services, including Shellfish Aquaculture.

FULL REPORT excluding Appendices

http://hdl.handle.net/10871/131804

Published 2022

Authors:

A. Ross Brown[a]; Donna Carless[a]; Ben Jackson[a] Ian Townsend[b]; Nick Paling[b]; Charles R. Tyler[a]

a. University of Exeter, College of Life and Environmental Sciences, Stocker Road, Exeter, Devon, EX44QD.

b. Westcountry Rivers Trust, Rain-Charm House, Kyl Cober Parc, Stoke Climsland, Callington, Cornwall, PL17 8PH.

Contents

1 Report outline

This 'wholescape' assessment of water quality in the Exe Estuary catchment has been completed as part of the South West Environmental and Economic Prosperity (SWEEP) aquaculture project https://sweep.ac.uk/portfolios/aquaculture/, which has the aim of supporting the sustainable expansion of aquaculture in SW England through integrated understanding and management of water quality issues at a whole catchment scale. The investigation focuses on the Exe Estuary catchment,extending from the sources of its rivers down to the Exe Estuary and into Lyme Bay (**Figure 1**).

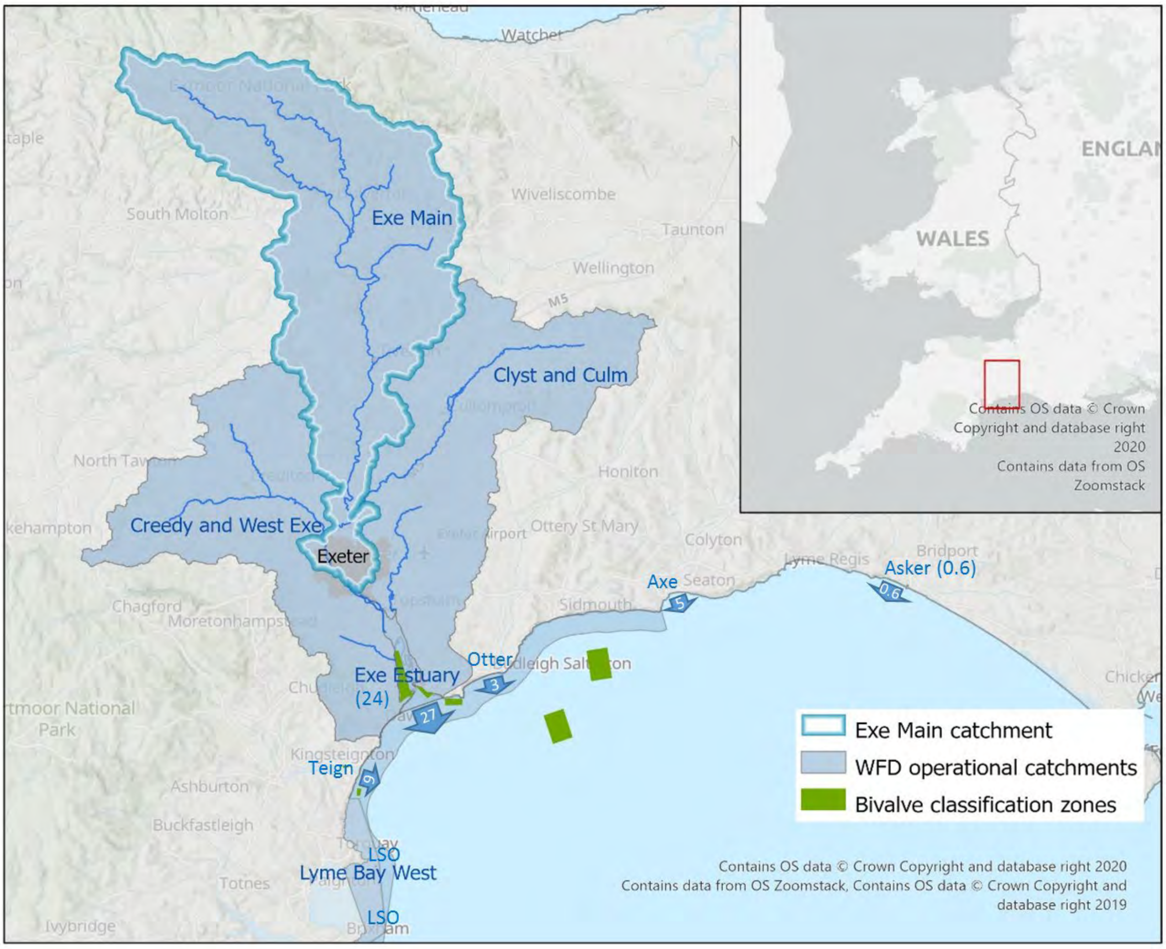
The report tracks the ecological, microbiological and chemical pollution status of these water courses and evaluates their impacts on estuarine and coastal shellfish, which are sensitive receptors, indicators (sentinels) and regulators (bio-remediators) of water quality, as well as highly sustainable food sources. We follow a similar (but finer grain) investigative approach to that undertaken in the Rivers Trusts' "State of our Rivers Report" for England (Rivers Trusts, 2021). As such we envisage that the following report will serve to inform a wide range of stakeholders in addition to the shellfish industry and regulatory authorities (e.g. bathing water users, water and tourism industries, and the general public).

The specific aims of this investigation are to provide an assessment of the current water quality of the Exe Estuary catchment, including tributaries of the Exe Estuary (**Figure 1**), assessing the drivers for water quality impairment, and impacts of this on estuarine and coastal bivalve shellfish aquaculture (farming of mussels, oysters and clams). This was done through a detailed evaluation of publicly available data and information. The investigation follows a receptor-pathway-source approach to back-track from designated shellfish waters in Lyme Bay and the Exe Estuary to potential upstream sources of contaminants in the Exe Estuary catchment. When reviewing information on potential sources and drivers of water quality issues, we highlight where there are significant data gaps. This report also provides a summary of activities and actions already underway within the wider catchment designed to achieve water quality improvements and discusses potential future catchment management interventions.

By taking a wholescape approach this assessment also attempts to address linkages between freshwater waters, estuarine and coastal waters in terms of their water quality status, the key pressures they face both locally and from up-stream, and the impacts that arise from these pressures. To date knowledge concerning these linkages has been limited by a lack of integrated assessments across the land-sea interface https://catchmentbasedapproach.org/learn/wamm/. A wholescape approach for joining up decision-making on land and at sea is now laid out in Marine Planning Policy and Integrated Coastal Zone Management, addressing the importance of land-sea interactions (HM Government, 2018a). This catchment investigation is one of the first case examples of a 'wholescape approach' being implemented in the UK.

Figure 1: The Exe Estuary catchment and tributaries feeding into the Exe Estuary and Lyme Bay

Water Framework Directive (WFD) operational catchments are highlighted in blue. Classification zones for bivalve shellfish production are shown in green. River discharges are labelled with their historical mean flow rates in m³ per second https://nrfa.ceh.ac.uk/data/search and two long-sea sewage outfalls (LSO) are also shown.



The process of the investigation involved collating and evaluating available water quality monitoring data in association with geospatial data on land uses and specific activities, including agriculture and aquaculture production, urban wastewater treatment and storm water management. This enabled information on water quality status, pressures and impacts to be compiled from various disparate data sources.

Available data and reports referred to in this investigation are listed in Bibliography. The investigation drew on various digital data sources in spreadsheet and Geographical Information System (GIS) formats, including from the following data hub websites:

- UK Centre for Ecology and Hydrology https://eip.ceh.ac.uk/hydrology/water-resources/
- Connecting the Culm https://connectingtheculm.com/; https://connectingtheculm.com/wp-content/uploads/2021/02/CtC-Evidence-Review-1stEdition-Feb2021_logos.pdf
- DEFRA MAGIC database https://magic.defra.gov.uk/
- Devon Local Nature Partnership https://www.devonlnp.org.uk/devons-environment/
- Dorset and East Devon Aquaculture https://www.dorsetaquaculture.co.uk/
- East Devon Catchment Partnership https://data.catchmentbasedapproach.org/pages/working-groups
- Environment Agency Catchment Data Explorer https://environment.data.gov.uk/catchment-planning/
- Environment Agency Water Quality Archive https://environment.data.gov.uk/water-quality/view/landing

- Exe Estuary Management Partnership https://www.exe-estuary.org/publications/state-of-the-exe-estuary/
- FSA Shellfish Classification https://www.food.gov.uk/business-guidance/shellfish-classification
- HM Government https://www.data.gov.uk/
- Lyme Bay Fisheries and Conservation Reserve https://www.lymebayreserve.co.uk/download-centre/
- Riverfly Partnership Data Explorer https://www.riverflies.org/content/DataExplorer
- SWW (data concerning metals, pesticides and pharmaceuticals in municipal wastewater
- The Rivers Trust https://www.theriverstrust.org/key-issues/sewage-in-rivers
- UK Water Industry Research - Chemicals Investigation Programme https://ukwir.org/my-ukwir-homepage
- Westcountry Rivers Trust https://www.theriverstrust.org/key-issues/state-of-our-rivers#main-content

2 Background and Context

2.1 Status of UK aquaculture and dependence of shellfish quality on water quality

Aquaculture is the fastest growing food production sector globally and, due to declining capture fisheries, it is expected to underpin sustainable economic growth in rural and coastal communities, including in the UK (DEFRA, 2015; FAO, 2020). Over the last 40 years in the UK the Aquaculture industry (shellfish and finfish) has seen considerable growth and is now a significant contributor to the UK economy with an annual value of £1.1 billion, equalling that of capture fisheries (OECD, 2021), with huge potential for future sustainable growth (DEFRA, 2015; Highlands and Islands Enterprise, 2017; Huntington and Cappell, 2020). The growth of UK aquaculture brings a number of socio-economic and environmental benefits, including the provision of sustainable long-term growth; employment opportunities; niche markets (e.g. for exotic species grown in bio-secure systems); additional ecosystem services beyond food production (e.g. nutrient regulation, habitat provisioning) (Huntington and Cappell, 2020; Pinn et al., 2021).

Growth in UK aquaculture to £1.1 billion per year (at point of first sale - OECD, 2021) has been dominated by Scotland, which holds 85% of the UK share, while the industry has stagnated in other UK countries (Hambrey and Evans 2016; Black and Hughes, 2017; Huntington and Cappell, 2020). For example, aquaculture has declined by 5.6% in England in the last decade due to a number of factors, including complex regulation and planning, low social acceptance and domestic consumption, lack of economic investment, growing climate and environmental challenges (Huntington and Cappell, 2020). Nevertheless SW England remains a major centre for aquaculture, containing over a third of production areas for shellfish in England and Wales (111 out of 331 areas, Food Standards Agency, 2022) and has considerable scope to diversify/expand (Maritime UK, 2020). The Exe estuary and neighbouring coastal waters produce some of the highest volumes of shellfish in the SW region (**Section 3**).

Some of the main environmental challenges faced by the industry are associated with impairment of water quality by various forms of pollution. As bivalve shellfish (e.g. mussels and oysters) process large volumes of water when filter feeding on plankton (3.4 and 34 litres per hour, respectively) (Newell, 2004), they can accumulate and retain in their flesh water-borne contaminants, including potentially harmful chemicals and pathogenic microorganisms (Campos et al., 2013; Cefas, 2013) (Brown et al., 2020; Webber et al., 2021). Furthermore, while planktonic primary production, fuelled by nutrients (nitrogen and phosphorus) underpins shellfish production, excessive nutrient inputs from land can lead to eutrophication and asphyxiation of shellfish, as shown historically in the Exe Estuary (Langstone et al., 2003). Thus bivalve shellfish are sensitive indicators of a wide range of pollutants (**Section 4**).

Maximum threshold concentrations for a range of organic and inorganic chemical contaminants in shellfish meat, for human consumption, are stipulated by EU Hygiene Regulations (EC, 2004a, b and c). Other priority substances listed in Annex II of Directive 2008/105/EC4; and synthetic compounds (biocides, pesticides, antifoulants, flame retardants and pharmaceuticals) are also monitored in shellfish under the Water Framework Directive (WFD: 2000/60/EC) and Oslo Paris Commission (Beyer et al., 2017). Priority substances regulated under the WFD, may impact on shellfish health and productivity, but these impacts are difficult to discern under current assessment regimes (**Section 4**). Land-derived faecal microbial contaminants can also accumulate in shellfish. While this may have limited direct impact on shellfish health and growth, some accumulated faecal bacteria (e.g. enterococci) and viruses (e.g. norovirus) can impact on the health of human consumers, if faecal indicator organisms (FIOs – *Escherichia coli* or *E. coli*) exceed statutory limits of 230 colony forming units per 100 g of shellfish flesh and intervalvular fluid) (EC, 2004c). This in turn can impact on the National Health Service, and on the shellfish industry, through loss of sales, product recalls and loss of consumer confidence (Campos and Lees, 2014; Hassard et al., 2017).

The loading/presence of chemical and faecal contaminants in estuarine and coastal waters may be related to multiple sources within the catchment and their relative importance may change depending on seasonal agricultural practices, climatic factors such as rainfall, in combination with catchment topography/geology and also hydrological factors, including tidal movements. According to Kay et al., (2010), urban (sewerage-related) sources are generally the dominant drivers of FIOs in UK rivers during base flow conditions e.g. in the summer, when there is little or no runoff from agricultural land, whereas during high river flows - improved grassland and associated livestock are the significant source of FIOs. Nevertheless, Combined Sewer Overflows (CSOs), Sanitary Sewer Overflows (SSOs) and Storm Tank Overflows (STOs) can also be significant contributors of FIOs and bacterially contaminated water during wet weather and high river flows (Crowther et al., 2016). The importance of agricultural and municipal sewage sources of contaminants in the Exe Estuary catchment are investigated in **Section 5**.

Flood events exacerbate water pollution, not only through increased land runoff, but also through the resuspension of sediments bearing chemical and microbial contaminants and nutrients (Gooday et al., 2014). Metals and some organic pollutants can persist in sediments for decades (Everaert et al., 2017). Faecal contaminants including *E.coli* can persist in freshwater and estuarine sediments for periods of several weeks (Davies et al., 1995; Perkins et al., 2016), thus obscuring FIO source tracking (Kay et al., 2010; Hassard et al., 2016). Other sources of animal-derived FIOs include terrestrial and aquatic wildlife populations, which may be significant in some cases, particularly for estuarine and coastal waters (Crowther et al., 2016; 2018). For example, some northern hemisphere estuaries, such as the Exe estuary regularly accommodate large populations of several thousand overwintering wildfowl and waders (WeBS, 2017) and cumulative inputs of FIOs can reach x10^{11}-10^{12} colony forming units every 24 hours (Davies et al., 1995; Perkins et al., 2016). Faecal contamination of shellfish (and bathing) waters in the Exe estuary and neighbouring coastal waters is related to multiple rural and urban land uses and sources in the catchment, which are examined in **Section 6**. Subsequent sections (**Sections 7-11**) of this report focus on range of chemical contaminants with the potential to impact on shellfish and environmental and human health more generally.

2.2 Legal framework for the protection of water quality in the UK

The protection of water quality in the UK has multiple strands, which relate to specific designated uses of water bodies, including nature conservation, drinking water abstraction, bathing, fisheries and shellfish production (**Appendix 1**). The protective legal framework for freshwaters, transitional waters (estuaries) and inshore coastal waters (up to 1 nautical mile offshore) is defined by the Water Framework Directive (WFD - 2000/60/EC), enacted in England and Wales by Environment (Water Framework Directive) (England and Wales) Regulations 2017 (Section 1.2.1). Protection of marine waters is afforded by the Marine Strategy Framework Directive (MSFD - 2008/56/EC) enacted in the UK by the Marine and Coastal Access Act (2009). These legal instruments are key components of the UK Environment Act (2021).

3 Overview of the Exe Estuary catchment draining into the Exe Estuary and Lyme Bay

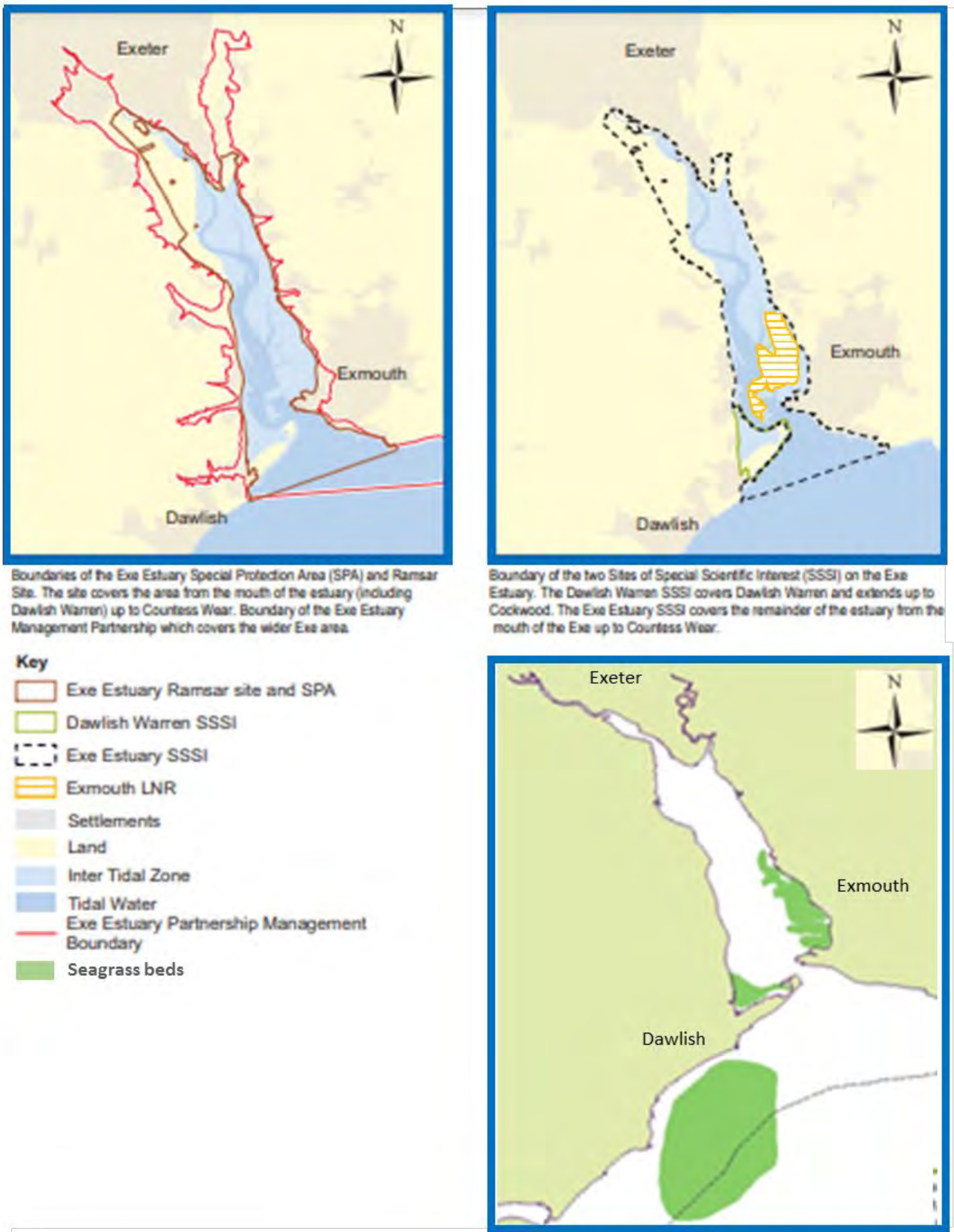
The following section of the report presents an overview of the location and character of protected shellfish waters in Lyme Bay and the Exe Estuary, briefly describes other protected areas (requiring water quality regulation), and looks back upstream to identify the various riverine inputs and anthropogenic discharges that influence water quality within the Exe Estuary catchment.

3.1 Lyme Bay

Lyme Bay extends eastwards for 65 km (35 nautical miles) from Start Point Lighthouse in Devon to Portland Bill Lighthouse in Dorset. The Bay contains a number of internationally important Marine Protected Areas, including the Lyme Bay and Torbay Special Area of Conservation and the East of Start Point Marine Conservation Zone. The coastline from the mouth of the Exe Estuary to Beer represents the East Devon Heritage Coast and is part of the wider Dorset and East Devon World Heritage Site ('Jurassic Coast'). Two WFD coastal waterbodies extend 1 nautical mile out to sea https://environment.data.gov.uk/catchment-planning/ManagementCatchment/3086 from the mean high spring tide water mark: Lyme Bay West (Dartmouth to Beer) and Lyme Bay East (Beer to Portland Bill). Broader coastal areas i.e. Marine Character Areas MCA 1 - Lyme Bay West and MCA 2 - Lyme Bay East extend from mean high water to 12 nautical miles offshore, to a water depth of 60 m (Marine Management Organisation, 2013). The Environmental Status of these marine areas is assessed and managed under the Marine Strategy Framework Directive – MSFD (2008/56/EC) and has attained 'Good' status (**Section 4.2**).

Lyme Bay West is typically less ecologically diverse compared to Lyme Bay East. Nevertheless, possibly the largest single seagrass site in England (~1,000 ha) is located here, comprising of a subtidal seagrass (*Zostera marina/angustifolia*) bed to the south of the Exe estuary (Devon Biodiversity Records Centre, 2005; Marine Management Organisation, 2016) (**Figure 2**). During the scoping of the Marine Management Organisation's South Marine Plan, covering Folkestone to the river Dart (HM Government, 2018a), sea grass (*Zostera spp.*) was found to occupy an area of 1,657 ha, i.e. 34% of the total UK seagrass coverage (4,887 ha; Luisetti et al., 2013). Using the same baseline calculation, the seagrass site in Lyme Bay may have historically (in 2005) supported ~20% of the total UK seagrass coverage, however more data are needed to corroborate this. Elsewhere in Lyme Bay West the seabed typically consists of fine sand and mud sediments, derived principally from rapidly eroding sandstone formations and from the rivers Teign and Exe (Munro, 2012). There are several nearshore and offshore sand banks, which are part of a dynamic, wave driven (predominantly east to west) long-shore sediment transport system (SCOPAC, 2013).

Figure 2. Marine Protected Areas and key habitat features in the Exe Estuary and Lyme Bay West



In Lyme Bay East river discharges are much smaller and tidal streams are markedly stronger. Consequently, the seabed is much rockier and sediments much coarser, which results in richer assemblages of filter feeding animals such as larger erect sponges, gorgonians, soft corals (Munro, 2012). Lyme Bay East MCA contains high-biodiversity reefs formed of mudstone, limestone, chalk and granite outcrops, pebbles, cobbles and boulders, listed under Annex I of the Habitats Directive (92/43/EEC). These reefs are home to protected species, including cold water corals such as the pink sea fan (*Eunicella verrucosa*) (listed under Schedule 5 of the UK Wildlife and Countryside Act 1981) and Ross coral (*Pentapora fascialis*). The exclusion of scallop (*Pecten maximus*) dredging and bottom trawling from the Lyme Bay Marine Protected Area (part of the Lyme Bay and Torbay SAC designated in 2008) has resulted in substantial recovery of listed species and broader benthic communities, which reached a peak from 2011-13 (Sheehan et al., 2013; 2021). The recovery was reversed temporarily by storms in the North Atlantic, which hit the southwest of the UK during the winter of 2013–2014 (Kendon, 2015) and some key commercial species (including *P. maximus*) remain in low abundance within the SAC and surrounding areas (Sheehan et al., 2021). Lyme Bay nevertheless supports a range of sediment and reef dwelling invertebrates including bristle worms, razor clams and mussels and provides important spawning/nursery grounds for number of fish species such as lemon sole (*Microstomus kitt*), sand eels (*Ammodytes tobianus*), mackerel (*Scombre scombrus*), thornback ray (*Raja clavata*) and spotted ray (*Raja montagui*) (Marine Management Organisation, 2020; Natural England, 2020a).

3.2 Exe Estuary

The Exe estuary is a bar-built ria estuary (flooded river valley), covering an area of 18 km^2 between its upper and lower tidal limits at Countess Wear and Exmouth, respectively. The estuary is surrounded by an additional area of 5.45 km^2 of wetlands (**Figure 2; Appendix 2**) giving a total area of 23.45 km^2 internationally protected wetlands under the Ramsar Convention (JNCC, 2008). The seaward end of the estuary is bounded by Dawlish Warren, a large, south-west to north-east orientated sand spit, 2.5 km long, 500 m wide and 1.4 to 6.0 m above Ordnance Datum (SCOPAC, 2013). Dawlish Warren has been protected by various sea defences incorporating sand, rock armour and groynes. The estuary is dredged regularly to maintain a navigable channel for private and commercial vessels and estuary margins include reclaimed land and additional tidal defences, as well as transport, commercial and recreational infrastructure. The estuary system is classified under the WFD as 'highly modified', (Environment Agency, 2013). Given the international conservation importance of the estuary, the WFD target is for the estuary to achieve 'Maximum Ecological Potential', taking into account its heavily modified status (2000/60/EC). The Estuary is currently classified as achieving Moderate Ecological Potential **(Section 4.1**).

Tidal currents funnel in and out of the narrow inlet between the end of Dawlish Warren spit and Exmouth. The estimated flushing time for the estuary is 6 days (Uncles, 2002). Ebb tides are considerably faster than corresponding, longer duration flood tides, with flows reaching 3 ms^{-1} during spring tides and 1 ms^{-1} during neap cycles (SCOPAC, 2013). These high velocities are capable of moving large quantities of sediment, up to medium sized sand. Sediments drifting into the inlet are flushed several kilometres seaward and wave action drives material back landward (Posford Duvivier, 1998a).

Sediment inputs to the estuary are dominated by marine sources, with both tidal currents and waves moving ~18,000 m^3 yr^{-1} of fine sand (in suspension) and coarse sand and gravel (as bedload) towards the estuary entrance (Posford Duvivier, 1998a and b). Fluvially derived sediment input is relatively low, with the main supply of river sediment (1900 m^3 yr^{-1}) coming from the River Exe (Posford Duvivier, 1999). The estuary is consequently highly turbid (with up to 25 g L-1 suspended solids in the upper estuary around Turf locks), leading to low levels of light penetration in the water column (Langstone, et al., 2003). Despite this primary production is exceptionally high, with chlorophyll concentrations generally exceeding 10 $\mu g\ L^{-1}$, and therefore indicating eutrophic conditions, which are symptomatic of excess nutrient inputs (**Section 7.1**). Nevertheless, dissolved oxygen levels often exceed 100% and the estuary contains diverse habitats for fauna and flora, including shallow intertidal flats, saltmarsh, seagrass and shellfish beds Langstone et al., 2003).

The estuary is an internationally important nature conservation area with multiple designations (**Figure 2**). The entire estuary and bordering marsh land (including Exminster and Bowling Green marshes) is a Ramsar protected wetland area and a European Marine Site/ Natura 2000 Site - Special Protection Area (SPA), owing to the presence of internationally important resident protected bird species and >20,000 migratory (over-wintering) wildfowl and waders (WeBS, 2017; Natural England, 2020b). The estuary is also a Site of Special Scientific Interest by virtue of its bird populations and rare plant species (mostly on Exminster Marshes), as well as nationally significant populations of invertebrates inhabiting the intertidal flats. The mudflats between Lympstone and Bull Hill bank, which support eel grass beds and invertebrates, including mussels and cockle beds are also designated as a Local Nature Reserve (EEMP, 2021).

3.3 The Exe Estuary catchment (non-tidal, freshwater)

The Exe Estuary catchment (1520 km^2) includes three operational catchments: the Exe main (655 km^2), the Clyst & Culm (460 km^2) to the east and the Creedy & West Exe (405 km^2) to the west. (Environment Agency, 2021b). **Appendix 3** contains a full list of water bodies in each of the three operational catchments. The River Exe rises on Exmoor at 450m above sea level and descends 82.7 km to Exmouth (JNCC, 2008). The River Creedy and River Culm drain into the River Exe, which subsequently drains into the Exe estuary at Countess Wear, while the River Clyst joins the estuary at Topsham and two other significant tributaries, the River Kenn and Polly Brook enter at Starcross and Exton, respectively. Mean river flow rates entering the Exe Estuary are substantially higher for the River Exe at Trews Weir (25 m^3/s) compared to the River Clyst (1.4 m^3/s), River Kenn (0.5 m^3/s) and Polly Brook (0.4 m^3/s) (Langstone et al., 2003; UK Centre for Ecology and Hydrology, 2021). All water courses draining into the Exe Estuary and into Lyme Bay West, with the potential to impact on the quality of shellfish (and bathing) waters therein, are listed in **Appendix 4**.

The Exe Estuary catchment falls within the Environment Agency's South West River Basin District and more specifically the East Devon Management Catchment. The East Devon management catchment (also including the Sid & Otter and Axe & Lim – which discharge directly to Lyme Bay) is primarily located in the county of Devon, although small areas in the North and East of the catchment are located in Somerset and Dorset respectively. The Exe catchment stretches from Exmoor and the Brendon Hills, to Exmouth in the south. The Blackdown Hills form the eastern boundary with the Haldon Ridge to the west.

The Exe Main catchment is largely rural and agricultural (**Table 1; Figure 3**) with significant population centres in Exeter and Tiverton. The main river system within the catchment is the River Exe (Source to River Creedy) and its tributaries the Rivers Barle, Quarme, Haddeo, Batherm and Lowman. The Exe, Barle and Quarme rise on Exmoor, within the Exmoor National Park, an area of moorland and wooded valleys before flowing in roughly a southerly direction before being joined by the Haddeo, Batherm and Lowman. In the upper catchment of the Exe the geology is predominantly Devonian siltstones and sandstones, with soils characterised by low permeability peaty soils. The more central areas of the catchment are dominated by improved grassland pasture for dairy and beef cows and sheep with some pigs and poultry and also arable land (cereals) in more fertile lowland areas. The soils consist of loamy subsoils over clay subsoils, which are generally slowly permeable (Westcountry Rivers Trust, 2014; East Devon Catchment Partnership, 2016).

The Creedy and West Exe catchment lies to the west of the Exe Main and is predominantly improved grassland pasture, with arable land (cereals) mainly in the lower catchment. Soils are relatively freely draining acid loamy soils over Permian mudstone siltstone or sandstone (Westcountry Rivers Trust, 2014). The main tributaries are the River Yeo which merges with the River Creedy near Crediton and meets the River Exe at Cowley Bridge near Exeter. The southern part of the catchment is coastal with a number of tidally influenced streams flowing into the Exe Estuary (East Devon Catchment Partnership, 2016). The most significant of these streams is the River Kenn, which rises in the Haldon Hills and flows for 14.2 km through Haldon Forest and agricultural land and receiving treated effluent from Kenton and Starcross sewage treatment works (STW), before entering the estuary between Starcross and Powderham.

The Clyst and Culm catchment lies to the east of the Exe Main catchment and is also mostly agricultural, but with a higher proportion of pigs and poultry and some light industry (building, energy generation, computer software and hardware) around Cullompton. The soils are slightly acid loam interspersed with poorly draining clay soils over Gault mudstone, sandstone and limestone (Westcountry Rivers Trust, 2014). The eastern part of this catchment falls within the Blackdown Hills area of outstanding natural beauty (AONB). The River Culm joins the main River Exe just north of Exeter, whilst the River Clyst rises near the village of Clyst William, near Cullompton and enters the Exe Estuary south of Topsham. Polly Brook is a smaller, but nevertheless significant tributary, rising east of Woodbury, then receiving treated sewage from Woodbury STW before flowing into the Exe Estuary at Exton.

Table 1: Agricultural land use classification in the Exe Estuary catchment based on UK CEH Land cover plus (incl. crops) – based on satellite imagery

Crop	Land area (km^2)
Grass	650.48
Winter wheat	52.02
Maize	46.95
Winter barley	27.30
Spring barley	14.27
Oilseed rape	10.24
Winter oats	7.74
Field beans	2.82
Spring wheat	2.49
Potatoes	1.53
Peas	0.39
Other crops	14.55

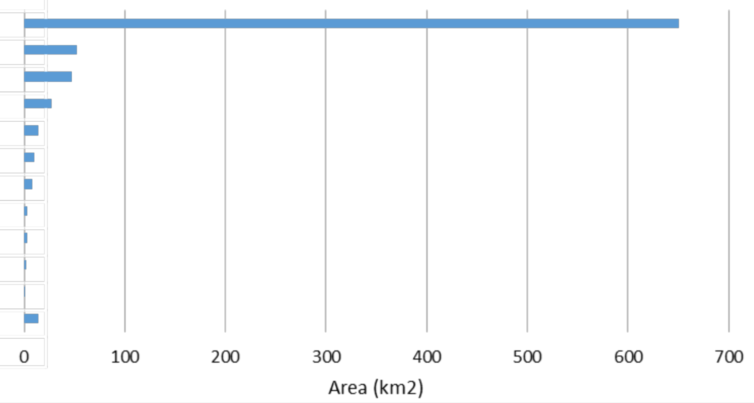
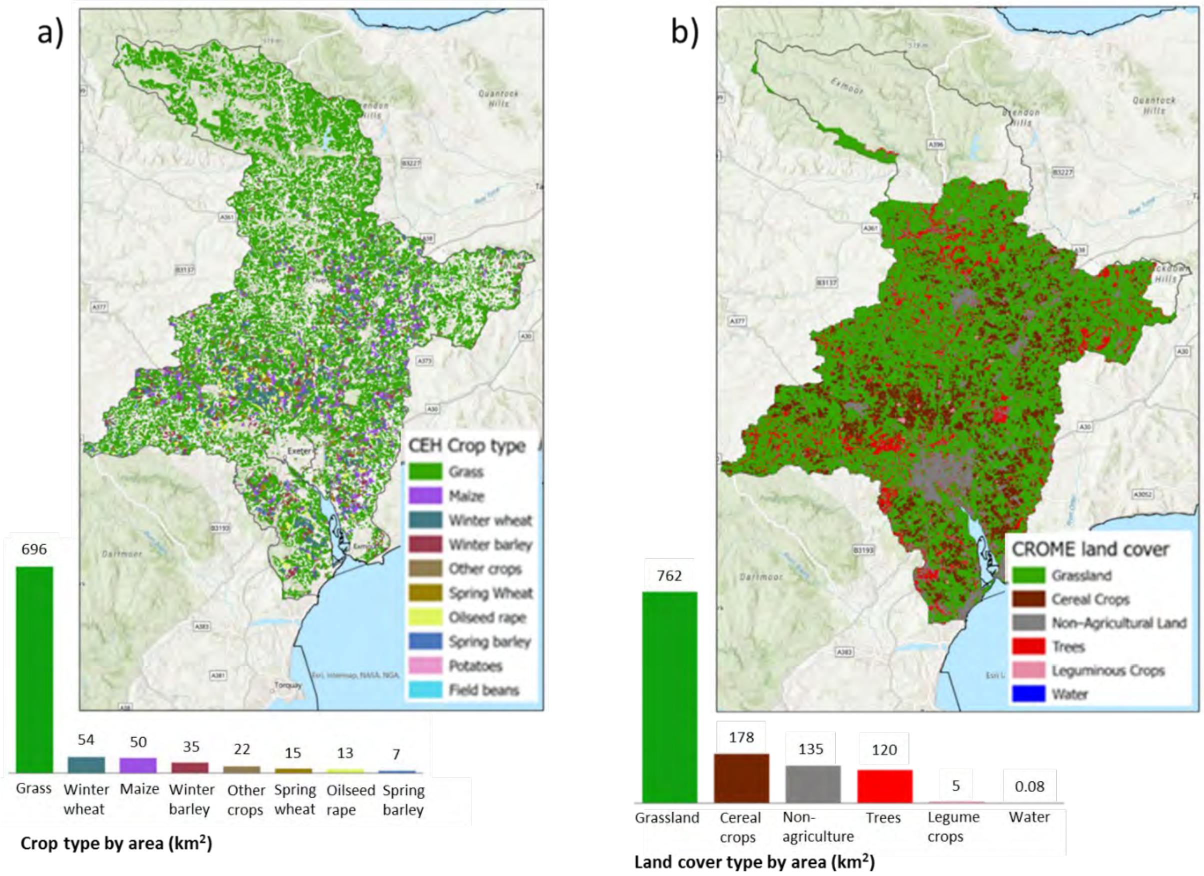


Figure 3: a) UK CEH Land Cover Plus and b) Crop Map of England (CROME) 2019 showing land use classification by crop type for the Exe Estuary catchment

https://www.ceh.ac.uk/services/ceh-land-cover-plus-crops-2015 https://data.gov.uk/dataset/8c5b635f-9b23-4f32-b12a-c080e3f455d0/crop-map-of-england-crome-2019



There are a number of sensitive ecological receptors in the Exe Estuary catchment, which are potentially susceptible to impaired water quality. These include the Exmoor Heaths Special Area of Conservation (SAC) and Exmoor and Quantock Oaks SAC, both located towards the north of the management catchment along with the Exmoor National Park. The East Devon and Blackdown Hills Areas of Outstanding Natural Beauty (AONB) are located in the South and East of the catchment. A number of SSSI designations are also distributed across the catchment. For example the South Exmoor SSSI containing the River Barle and its tributaries with submerged plants such as alternate watermilfoil (*Myriophyllum alterniflorum*). The North Exmoor SSSI is nationally important for its south-western lowland heath communities and for transitions from ancient semi-natural woodland through upland heath to blanket mire, which regulates water entering the upper catchment. The upper Exe also supports salmon and fishing is permitted in the Exe and the Barle.

4 Classification of water quality and shellfish quality

4.1 Water Framework Directive classifications

Water quality classification under the WFD is based on ecological status, chemical status and hydro-morphological status. Overall water quality classification follows a 'one out, all out' approach in which the lowest scoring biological and/or chemical element determines whether a water body passes or fails to achieve its desired water quality objective. In general the objective is to achieve 'Good' status or potential overall, while water bodies containing conservation features of international importance (Natura 2000 sites) are required to achieve 'High' ecological status, or in the case of the heavily hydro-morphologically modified Exe Estuary, they must achieve 'Maximum ecological potential'. To have an overall high status (or reference condition), a water body needs to comply with all the criteria monitored: biological, physical and chemical.

According to the most recent data for the South West River Basin District (latest data to 14 September 2021) - 206 out 697 (29.5%) of water bodies in the District have achieved 'Good' ecological status or higher to date (tranches 1 and 2 combined) (**Appendix 5.1**). This compares with 14% of all water bodies across England achieving the same objective (Environment Agency, 2021b) (**Figure 4**).

WFD assessment data specifically for the Exe Estuary catchment, including each of the operational catchments within it (Clyst & Culm; Creedy & West Exe; Exe main; Exe Estuary; Lyme Bay (West) show that only 12 out of 64 (18.75%) of water bodies (from the Creedy and West Exe and Exe main catchments) currently achieve 'Good' ecological status or higher (**Appendix 5.2; Figure 5**). Predominant reasons for not achieving good (RNAG) ecological status/potential include agriculture and rural land management - pollution; urban and transport - pollution; water industry – pollution from waste water.
https://environment.data.gov.uk/catchment-planning/ManagementCatchment/3033/rnags

Figure 4: Proportion of water bodies with Good ecological status or higher in England, SW England and the Exe Estuary catchment (2019)

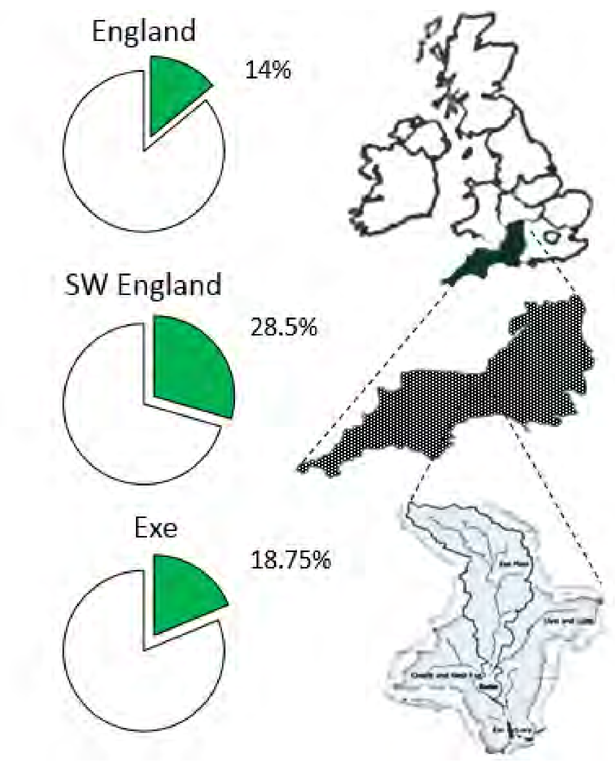
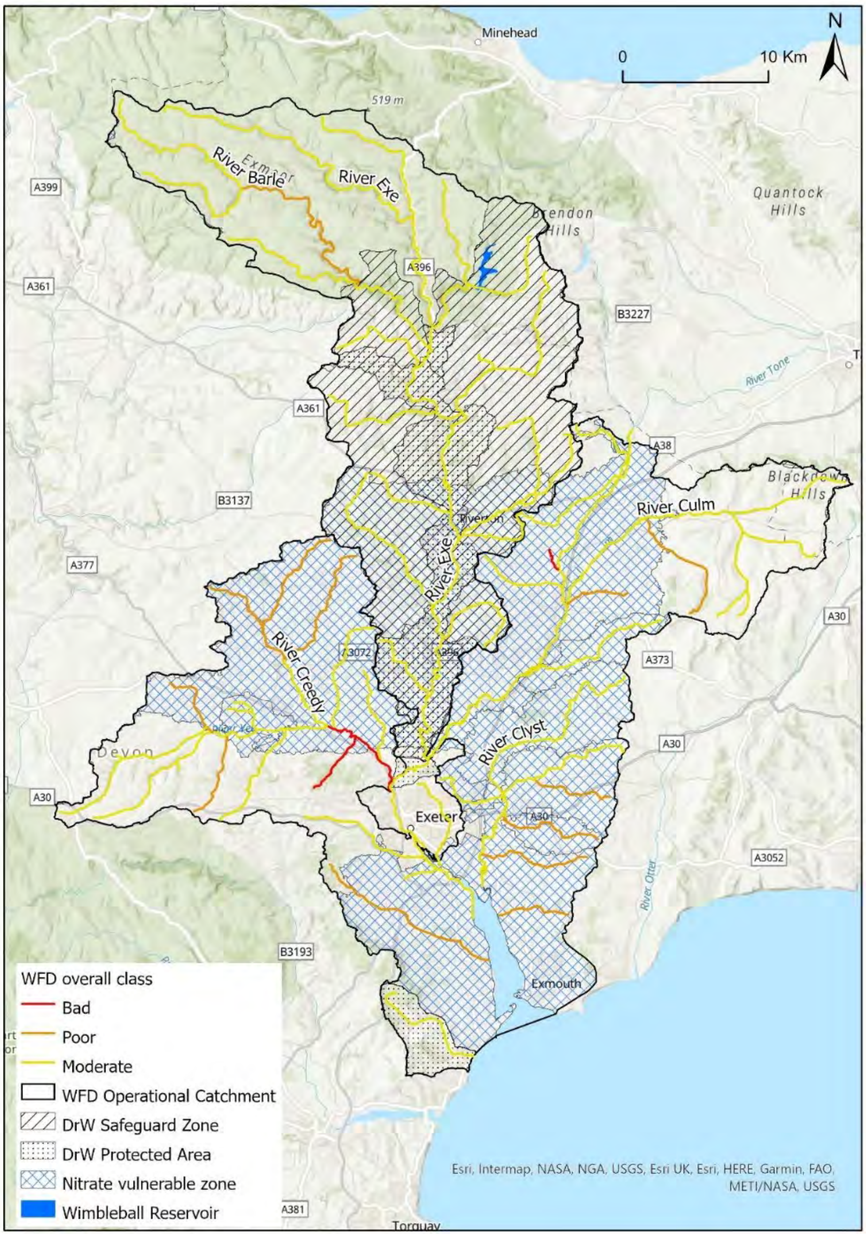


Figure 5: Water Framework Directive (WFD) classification of Ecological Status of rivers in the Exe Estuary catchment in 2019



All water bodies in the Exe Estuary catchment (and all others in the UK) currently fail to meet 'Good' chemical status (**Appendix 5.3**). Reasons for not achieving good (RNAG) chemical status include: exceedance of Environmental Quality Standards (EQS_{biota}) for: a) poly-brominated diphenyl ethers (PBDEs) EQS_{biota} = 0.0085 μg/kg; b) mercury and its compounds EQS_{biota} = 20 μg/kg. Chemicals a) and b) have recently been detected up to 2500× the EQS_{biota} for PBDEs and up to 10× the EQS_{biota} for mercury in signal crayfish (*Pacifastacus leniusculus*) in freshwaters and/or blue mussels (*Mytilus edulis*) in transitional and coastal waters in the UK (Environment Agency, 2019a; 2019b; 2021a). Sources of these chemicals are largely atmospheric pollution. Additional reasons for not achieving good (RNAG) chemical status, for named water bodies in the Exe Estuary catchment include: c) benzo[ghi]perylene (in Lower Batherm in Exe Main catchment and Exe Estuary). These chemicals a, b and c are priority hazardous substances listed under the WFD (Environment Agency, 2021b).

4.2 Marine Strategy Framework Directive classifications (relating to nutrient and chemical pollution)

The South Marine Plan states that "Much of the economic and cultural prosperity of the South Marine Plan areas is reliant on water quality". Marine Plan Policies S-WQ-1 and S-WQ-2 seek to manage impacts on water quality, and the habitats and species which benefit water quality through the ecosystem services they provide (**Section 5.1**).

According to the UK updated assessment and Good Environmental Status under the Marine Strategy water quality-related GES descriptors (**Appendix 6**) indicate that Good status has been achieved in the majority of areas (DEFRA, 2019). Some estuarine and coastal waters continue to exhibit eutrophication problems (21 problem areas, and 11 potential problem areas, rewspectively). These areas represent a small proportion of the total area of UK waters (0.03%) and of 0.41% of estuarine and coastal waters. Concentrations of hazardous substances and their biological effects in the Celtic Regional Sea Area (including Lyme Bay) are generally lower than thresholds that cause harm to sea life, and are not increasing (89% compliance for contaminant concentrations and 96% compliance for biological effects). The few failures are caused by highly persistent legacy chemicals such as PCBs in biota and marine sediments mainly in coastal waters and often close to polluted sources.

Oslo Paris Commission (OSPAR) criteria for contaminants in biota, including mussels (**Appendix 7**) are used to assess progress against the targets for Good Environmental Status (GES) set out in the UK's Marine Strategy (DEFRA, 2019), which requires that concentrations of substances identified within relevant legislation and international obligations are below levels at which adverse effects are likely to occur to sea life. OSPAR Environmental Assessment Criteria (EACs) represent contaminant concentrations in bivalve shellfish below which adverse environmental effects are avoided, including secondary poisoning in organisms that consume bivalve shellfish i.e. fish, birds and marine mammals (OSPAR, 2021).

Shellfish monitoring results for blue mussels at Exmouth (Beacon Point) in 2016 showed mercury concentrations (27 μg/L) to be marginally above the EAC (22 μg/L). More recent shellfish monitoring results gathered by the Environment Agency for blue mussels from Exmouth (Cockwood Harbour) in 2019 showed that mercury (26 μg/L) was again marginally above the EAC and may therefore present an environmental risk. From the 2019 data it is not clear whether Tri-butyl tin may also pose an environmental risk, since the detection limit (<20 μg/L) was above the EAC (15.2 μg/L) (**Table 2**). All other measured contaminants were below EAC values (OSPAR, 2021).

4.3 EU Food hygiene regulations relating to chemical contaminants

EU hygiene Regulation (EC) No 1881/2006) administered by the Food Standards Agency also sets maximum permitted levels of contaminants in bivalve shellfish to safeguard human consumers. Concentrations of specified contaminants in fish and other seafood caught or harvested for human consumption in UK seas generally do not exceed agreed safety levels. The most recent shellfish monitoring results gathered by the Food Standards Agency for blue mussels from Exmouth (Beacon Point) in 2015 indicate that heavy metals (including mercury) and PAHs are below maximum permitted levels (MPLs). Total concentrations of poly brominated diphenyl ethers (SBDE6 = 0.203 μg/L) exceeded the human health EAC (0.0085 μg/L) set by OSPAR by a factor of more than 20 (**Table 2**).

Table 2: Chemical contaminants in mussels sampled from Exmouth in 2015 and 2019

***Site S1**: Exe Approaches - Beacon Point, NGR: SX99698050, Date: 12/01/2015; Source: FSA, 2015*
***Site S2**: Exe West - Sandy Bay, NGR: SY02247907, Date: 18/02/2019; Source: EA, 2019*
***Site S3**: Starcross - Cockwood Harbour, NGR SX99698050, Date: 21/02/2019, Source: EA, 2019*
Standards:

- *Maximum permitted levels (MPLs) in bivalve shellfish according to Contaminants in foodstuffs Regulation (EC) 1881/2006. PBDE human health standard [d] corresponds to the EQS (2013/39/EU)*
- *Environmental Assessment Criteria (EACs) according to OSPAR (2021).*

EACs correspond with the following standards (depending on the chemical):
[a] EQS_{biota} (bivalve shellfish) (2008/105/EC), [b] OSPAR Quality Standard based on secondary poisoning;
[c] OSPAR Quality Standard for fish muscle; Measured values above EACs highlighted in RED.

Chemical group	Chemical	Concentration in mussels (µg/kg wet weight)				
		Measured S1 - 2015	Measured S2 - 2019	Measured S3 - 2019	MPL	EAC
Poly aromatic hydrocarbons	Benzo[a]pyrene	1.42	3.50	1.02	10	5[a]
	Benzo[a]anthracene	2.51	1.41	1.04	10	-
	Chrysene	2.4	1.80	1.36	10	-
	Benzo[b]fluoranthene	4.65	3.37	3.41	10	-
	Benzo(g,h,i)perylene	-	26.7	0.635	-	-
	Benzo(k)fluoranthene	-	1.42	1.35	-	
	Fluoranthene	-	3.54	4.23	-	-
	Phenanthrene	-	1.30	4.64	-	-
	Naphthalene	-	<1	<1	-	-
	Anthracene	-	<0.5	<0.5	-	-
	Pyrene	-	4.18	<0.5	-	-
	Indeno(1,2,3-cd)pyrene	-	2.90	4.33	-	-
Metals	Cadmium (Cd)	137	90	179	1000	160[b]
	Mercury (Hg)	**27**	**26**	**31.1**	500	**22[b]**
	Lead (Pb)	499	314	391	1500	1000[b]
Dioxins	Sum of dioxins	-	-	-	4	0.0012[b]
	Sum of dioxins & PCBs	-	-	-	8	0.0012[b]
	Sum of ICES 7 PCBs	-	-	-	-	0.075[c]
Poly chlorinated biphenyls	PCB - 028	-	<0.5	<0.1	-	67
	PCB - 052	-	0.117	<0.1	-	108
	PCB - 101	-	0.234	<0.1	-	121
	PCB - 118	-	0.299	0.119	-	25
	PCB - 138	-	0.459	0.205	-	317
	PCB - 153	-	0.651	0.282	-	1585
	PCB - 180	-	<0.1	<0.1	-	469
Organo chlorines	DDT -pp	-	0.103	<0.1	-	-
	DDE -pp	-	0.515	0.243	-	-
	TDE -pp	-	0.103	<0.1	-	-
	Hexachlorobenzene	-	0.133	<0.1	-	10
Poly brominated diphenyl ethers	BDE28	-	<0.006	0.007	-	120
	BDE47	-	0.093	0.041	-	44
	BDE99	-	0.060	0.029	-	1
	BDE100	-	0.031	0.015	-	1
	BDE153	-	<0.02	<0.02	-	4
	BDE154	-	0.019	<0.01	-	4
	SBDE6 (sum of 6 BDEs)	-	**0.203**	**0.85**	**0.0085[d]**	44
Tri butyl tin	TBT	-	**<20**	**<20**	-	**15.2[b]**

4.4 Classification of shellfish waters (relating to faecal pollution)

The shellfish waters of the Exe Estuary (and the majority i.e. ~90% of shellfish waters in England and Wales) are classified under the EU Hygiene Regulations (EC) No. 854/2004 as being Class B (≤ 4600 *E. coli* / 100 g of shellfish flesh and intravalvular fluid), requiring shellfish depuration. This classification and the lack of purification facilities currently prevents the export of shellfish to EU countries, which is the largest single market for these food products produced in the UK (Food Standards Agency, 2021). Designated shellfish waters located 3-10 km offshore in Lyme Bay have also been reported to be impacted occasionally by elevated *E. coli* concentrations in shellfish, leading to seasonal downgrading from Class A to Class B (**Table 3**). The sources of this faecal contamination remain unknown (Land et al., 2022).

Table 3: Classification of shellfish waters based on faecal indicator organism (FIO) counts in bivalve shellfish (minimum of 10 samples required per year for Class A; 8 samples for Class B & C)

Class	*E. coli* mean probable number /100g shellfish flesh	Treatment required
A	≤ 230 (80% of sample results) < 700 (100% of sample results)	May go direct for human consumption
B	≤ 4600 (90% of sample results) < 46000 (100% of sample results)	Must be depurated, heat treated or relaid to meet Class A
C	≤ 46000 (100% of sample results)	Must be laid for at least 2 months, followed where necessary by treatment in a Purification Centre to meet Class A requirements
P	> 46000	Prohibited from production or collection

Under the EU Hygiene Regulations (EC) No. 854/2004, Official Control Measures require that all shellfish harvesting areas undergo sanitary surveys to provide the best available information and evidence for hygiene classification zoning and monitoring (based on *E. coli* counts in shellfish) to ensure public health protection (CEFAS, 2013; FSA, 2021). The findings of recent sanitary surveys for shellfish waters in Lyme Bay (West) and the Exe Estuary are summarised below.

4.4.1 Lyme Bay (West)

There are four coastal shellfish production sites located in Lyme Bay (West) (**Figure 2**), each employing long lines for farming blue mussels (*Mytilus edulis*). Two sites lie inshore, one in Tor Bay and one in Labrador Bay, and both hold long-term B classifications based on *E. coli* counts in the shellfish flesh (**Table 4**). The remaining two sites are Lyme Bay Site 1 (10 km offshore) and Lyme Bay Site 2 (3 km offshore), which hold seasonal A/B and long-term A classifications, respectively. Seasonal downgrading of Site 1 (during the winter) is due to occasional elevated FIO counts (>230 *E. coli*/100 g of shellfish flesh). This has prevented the export of mussels from this site during the winter to the farm's principal market in the European Union (EU). The offshore sites are only partially developed. According to the Marine Management Organisation planning consent, the offshore sites will merge, extending over 15 km^2 and production is expected to increase from 3,000 up to 10,000 tonnes of mussels each year, making it the highest production shellfish site in the UK.

The existing offshore mussel farms in Lyme Bay (Sites 1 and 2) been shown to attract a high diversity of other flora and fauna. In particular these include large shoals of Atlantic horse mackerel (*Trachurus trachurus*), European bass (*Dicentrarchus labrax*) and grey mullet (*Chelon labrosus*). Commercially important brown crab (*Cancer pagurus*) and lobster (*Homarus gammarus*) are also present in high abundance and feed on the mussels, which fall to the sea bed below the suspended mussel farm (Sheehan et al., 2019). The offshore mussel farms regularly attracts numerous fishing boats that deploy static and towed fishing gear around its perimeter. The development of the farm has also been anecdotally reported to coincide with increased spat settlement and juvenile mussel recruitment in Lyme Bay (Holmyard pers. comm.).

Table 4: Location and classification status of shellfish production sites in Lyme Bay West (W) and the Exe estuary (FSA, 2021; Carcinus, 2021)
E. coli counts are per 100 g of shellfish flesh and intervalvular fluid.

*Classification follows EU Hygiene Regulations (EC) No. 854/2004 (see **Table 3**)*

Location	Representative Monitoring Point	FSA Ref	National Grid Reference	Distance offshore (km)	*E. coli* count (min-max)	*E. coli* count (mean)	Class
Lyme Bay W	Site 1	B090M	SY13687543	9	18-35000	54	A/B
Lyme Bay W	Site 2	B090P		3	18-3300	42	A
Lyme Bay W	Labrador Bay	B27AI	SX94087054	0.5	18-24000	125	B
Tor Bay	Fishcombe	B082B	SX90965741	0.2	18-35000	129	B
Exe Estuary – Exe Approaches	Beacon Point	B26AT	SX99698050	-	18-7900	218	B
Exe Estuary – Dawlish to Starcross	Cockwood Harbour	B26BH	SX97948072	-	18-24000	346	B
Exe Estuary – Sandy Bay	Sandy Bay	B26BJ	SY02247907	-	18-13000	836	B
Exe Estuary - Lympstone	Lympstone	J0591	SX98818314	-	N/A	N/A	B
Exe Estuary – Starcross to Powderham	River Kenn	B26BC	SX97638313	-	330-24000	1489	P
Exe Estuary – Public beds	N/A	N/A	N/A	-	N/A	N/A	P

4.4.2 Exe Estuary

The Exe estuary contains six shellfish areas (**Table 4**), including naturally occuring shellfish beds, relayed/bottom grown and trestle grown shellfish (Kershaw and Acornley, 2009; Carcinus, 2021; Food Standards Agency, 2022).

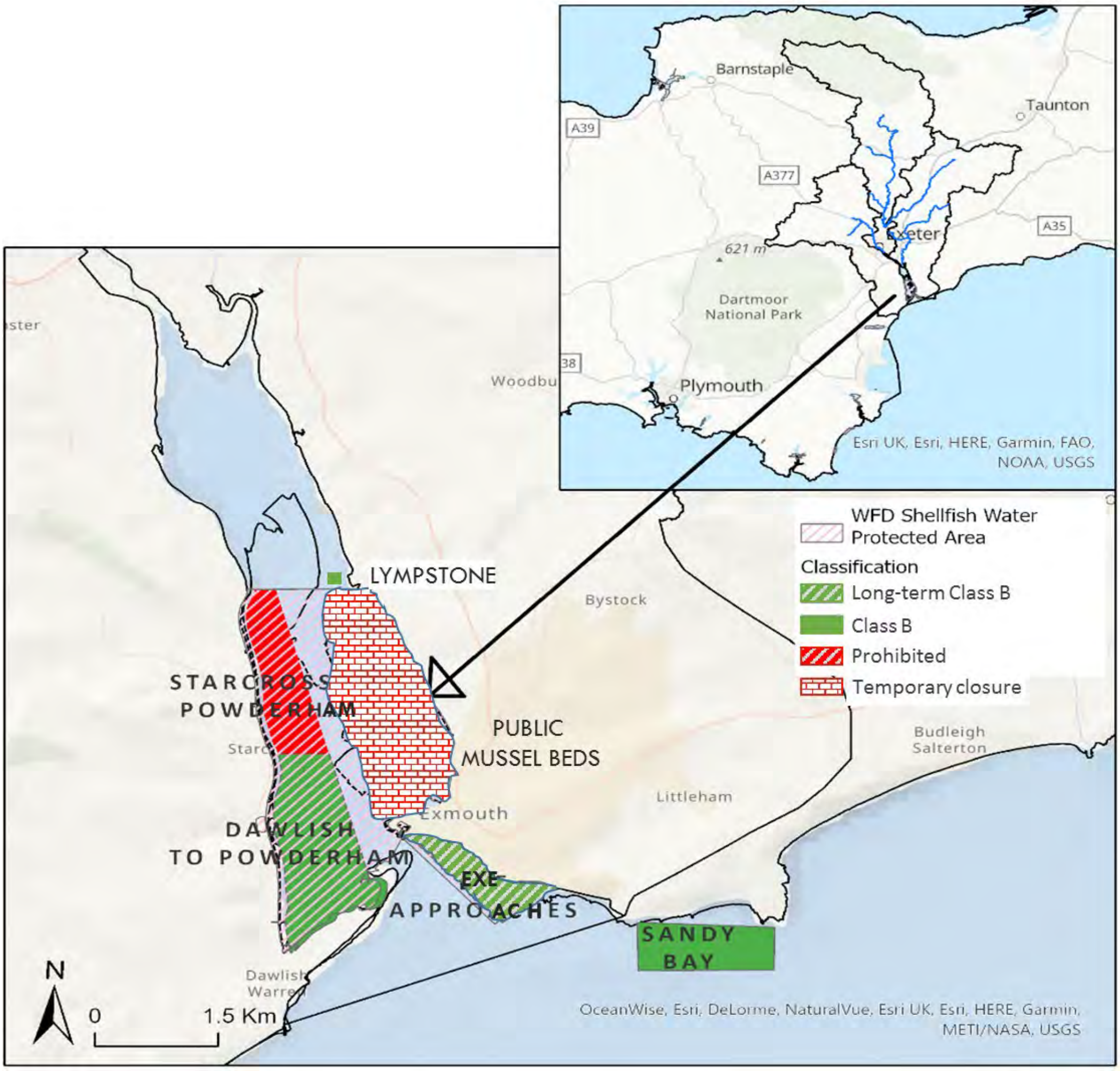
Three shellfish areas are currently closed for food production: i) Powderham to Starcross is prohibited following the recording of high *E. coli* levels in shellfish at the representative monitoring point (River Kenn - B36BC) in 2015, but is now being developed as a native oyster (*Ostrea edulis*) culture site (Aquafish Solutions, 2021); ii) Sandy Bay has recently been declassified (wild surf clams - *Spisula solida*); iii) Public mussel beds (*Mytilus edulis*) in the centre of the estuary remain closed following severe scouring of the beds by storms in the winter of 2013/2014 – reducing them from 20 ha equivalent to 2000 tonnes in 2013 to approximately 2.5 ha and <1 tonne in June 2019 - Devon & Severn IFCA, 2019)

Three shellfish areas are currently classified for food production: iv) Exe Approaches at the estuary mouth containing wild mussels - *Mytilus edulis*); v) Dawlish Warren to Starcross with relayed/ranched mussels and vi) Lympstone with farmed Pacific oyster (*Magallana gigas*) and Atlantic oyster (*Ostrea* *edulis*). These three areas are classified as Class B or long-term Class B (>5 years compliance), based on Official Control monitoring of FIO concentrations in shellfish samples (**Table 3**) obtained each month from representative monitoring points (RMPs) (**Table 4; Figure 3**).

Cockwood Harbour, located between Dawlish Warren and Starcross, is the main shellfish aquaculture area and has been classified since 2013 for relaying and growing 150-170 tonnes of mussels per year, with potential to increase this to 2,500 tonnes (CEFAS, 2013). Mussels are relaid and harvested on a two year rotation by Exmouth Mussels Ltd. using fluidised suction dredging. The area is also classified for growing and harvesting of Pacific oysters (Carcinus, 2021). Recent increases in sedimentation in this area has impacted on shellfish survival and growth, particularly affecting recently laid mussels and causing Exmouth Mussels Ltd. to reduce production substantially. Exmouth Mussels Ltd. have intimated this may have been due to the flood defence work at Dawlish Warren in 2016/17, which was followed by the errosion of Bull Hill sand bank. Annual mussel stock assessments are being conducted by Devon and Severn IFCA to see if the sedimentation and/or the reduction in relaying are impacting mussel populations and biodiversity in general throughout the estuary.

Stock assessments have demonstrated the ecological importance of bivalve shellfish in the Exe Estuary. The decline of natural and farmed mussel beds (following 2013/14 winter storms) appears to have led to increasing levels of suspended sediment and smothering of the bed of the estuary at Exmouth and Cockwood Harbour (Devon and Severn IFCA, 2021). In turn the loss of mussel reef habitat has impacted other invertebrates and reduced valuable food sources for fish and protected water birds (Devon and Severn IFCA, 2021). Exmouth Mussels Ltd. have previously relayed a proportion of their stock intertidally to increase food availability for the over-wintering bird species, for which the estuary is designated as a SPA. The ecological impacts of reduced relaying operations by Exmouth Mussels Ltd. around Cockwood Harbour (as a result of increased sedimentation) have not been assessed fully (Devon and Severn IFCA, 2021).

Figure 3. Shellfish protection zone and shellfish classification zones



4.5 Bathing water classification (relating to faecal pollution)

Bathing water protected areas are those in which a large number of people (100 or more people) are expected to bathe at any one time. There are 29 bathing water areas in Lyme Bay West (between Dartmouth and Beer); 18 are located between Hope's Nose (Torquay) and Beer and 2 of these are located at the mouth of the Exe Estuary. Under the UK Bathing Water Regulations 2013 (SI:1675, enacting the EU Bathing Water Directive 2006/7/EC), waters must be tested for faecal indicator organisms (FIOs – *E. coli* and/or intestinal enterococci) at weekly intervals between 1 May and 30 September, with a minimum of 20 samples tested annually. There are three measurement criteria for each FIO, including a minimum standard, which is sufficient for a bathing area to pass and standards of Good and Excellent water quality (**Table 5**).

The designated bathing waters at Exmouth and Dawlish Warren have historically (up to 2019) been awarded a Blue Flag for excellent bathing water quality. There was a pause in water quality sampling and classification in 2020 (due to the COVID pandemic). Sampling has subsequently resumed on a weekly basis during the bathing season (most recently between May 1st 2021 and Sep 30th 2021) and regularly achieve Excellent bathing water quality with respect to faecal indicator organisms (*E. coli* and intestinal enterococci) (**Table 5**). However, water quality testing has shown that the bathing waters occasionally experience short-term faecal pollution (HM Government, 2021a). The Environment Agency provides a daily pollution risk forecast for bathing waters based on the effects of rain and seasonality on bathing water quality. These factors affect the levels of bacteria that get washed into the sea from livestock, sewage overflows and urban drainage via rivers and streams. When these factors combine to make short term pollution likely, a pollution risk warning is issued via the following website (https://environment.data.gov.uk/bwq/profiles/help-understanding-data.html) and beach managers will display a sign advising against bathing. For beaches in Devon and Cornwall, pollution risk forecasts provided by the Environment Agency (and Surfers Against Sewage), come from South West Water, who also publicise the forecasts via BeachLive https://www.beachwise.org.uk/beachlive/. Given that more people are now swimming outside the normal bathing season, South West Water are considering year round alerts via BeachLive in the near future.

Table 5: Standards for coastal and transitional waters

[A]Based upon a 95-percentile evaluation; [B]Based upon a 90-percentile evaluation.

Faecal Indicator Organism	Classifications based on number of colony forming units per 100 mL of water		
	"Excellent"	"Good"	"Sufficient"
Intestinal enterococci	100[A]	200[A]	185[B]
Escherichia coli	250[A]	500[A]	500[B]

4.6 Drinking water classification (relating to chemical pollution)

1.6: Drinking water protected areas

Drinking Water Protected Areas (Surface Water) are areas in which raw water is abstracted for drinking water supplies from rivers and reservoirs. There are three Drinking Water Protected Areas (DrWPAs) in the Exe Estuary catchment, which cover a total area of 113.6 km^2 (17.3% of the Exe Estuary catchment – 655 km^2): Exe (Barle to Culm - GB108045015050) 103.2 km^2; Exe (Haddeo to Barle - GB108045015060) 3.7 km^2 ha; Exe (Culm to Creedy - GB108045009060) 6.9 km^2; plus Budleigh Brook, Dawlish Water, West Lyn River and the Bray. Drinking water from these areas is abstracted from the River Exe and treated at two water treatment works; Allers WTW located upstream of Tiverton and Pynes WTW located upstream of Exeter (SWW, 2019). Potential drinking water pollutants requiring monitoring, management/treatment are listed in **Appendix 1** and include a wide range of agents including faecal bacteria (*E. coli* and Enterococci), nitrate, heavy metals, pesticides and aromatic hydrocarbons.

According to recent Environment Agency monitoring data (Environment Agency, 2021b), Drinking Water Protected areas in the Exe (Barle to Culm - GB108045015050) and Creedy and West Exe (YEO

US Over Compton - GB108052015681) are at risk from a range of contaminants, which sometimes exceed the Drinking Water Directive standard of 0.1 μg/L (**Table 6**).

Table 6: Pesticides highlighted as presenting risk to drinking water protected areas in the Exe main catchment (Ian Townsend WRT, pers. comm.; Environment Agency, 2021b)

Chemical	**Status**	**Action**
Area - Exe (Barle to Culm)		
Atrazine	Banned in 2004	Not detected in Exe in 25+ yrs
Chlorotoluron	Further monitoring/investigations needed to confirm risk	Agriculture and rural land management via CSF
Diazinon	Still approved for use as an acaricide in sheep dipping	Monitor concentrations
Dicamba	Further monitoring/investigations needed to confirm risk	Agriculture and rural land management via CSF
Isoproturon	Banned, to be withdrawn from use	Monitor declining concentrations
MCPA	Further monitoring/investigations needed to confirm risk	Agriculture and rural land management via CSF
Mecoprop-P	Active optical isomer of mecoprop is still registered for use.	Monitor concentrations
Area - YEO US Over Compton		
Atrazine	Banned in 2004	Not detected Exe catchment in 25+ yrs
Simazine	Banned in 2004	Not detected Exe catchment in 25+ yrs
MCPA	Further monitoring/investigations needed to confirm risk	Agriculture and rural land management via CSF
Bentazone	Further monitoring/investigations needed to confirm risk	Agriculture and rural land management via CSF
Chlortoluron	Further monitoring/investigations needed to confirm risk	Agriculture and rural land management via CSF
Isoproturon	Banned, withdrawn from use	Not detected in Exe catchment since 2016
Diuron	Banned, withdrawn from use	Not detected in Exe catchment since 2013

An additional area of 402 km^2 (61.4%) of the Exe Estuary catchment constitutes a Surface Water Safeguard Zone (SWSGZ5012), which surrounds the above Drinking Water Protected areas, and is also highlighted to be at risk from pesticides (in particular: Chlorotoluron, MCPA, Mecoprop, Metaldehyde and Triclopyr) (Environment Agency, 2021c). The physical-chemical properties underlying the mobility (leachability) of these chemicals in soil are summarised in **Appendix 8**. Although the Granular Activated Carbon (GAC) treatment installed at Pynes Water Treatment Works and Allers Water Treatment Works in 2006 was initially extremely effective in removing pesticides from the raw water, after about 12 to 18 months South West Water began to find low levels of pesticides coming through into the treated water (**Appendix 9**). Pesticides, including metaldehyde, are confidently attributed to ongoing human activity (mainly agricultural use) in the catchment of the River Exe. The only pesticide to regularly appear in treated water from Allers/Pynes WTWs has been metaldehyde (generally <20ng/l). This pesticide is well known to not be efficiently removed by GAC (Townsend pers. comm.).

4.7 Classification of Nitrate Vulnerable Zones

There are four Nitrate Vulnerable Zones (NVZs) in the Exe main catchment, which are highlighted as being at risk from agricultural nitrate pollution:

S535	Aylesbeare Stream	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/9e38eec537ec47dcbc0875e7122d206b/data
S536	Clyst	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/a07bcb1ef5304e239c81bbb794ef09e3/data
S537	River Weaver	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/e51d26fec9384380a6f1d3926b5831fb/data
S538	Yeo (Creedy)	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/b2f0ce62c14646a7a4edf813035cce83/data

The 2019 WFD classification for the Exe Estuary based on dissolved inorganic nitrogen concentrations was 'Moderate' (Environment Agency, 2021b). Reasons for not achieving the WFD objective of 'Good' for this chemical quality element include nitrogen inputs from agricultural land, including arable land and grassland holding livestock, and also from municipal waste water discharges. The corresponding 2019 WFD classification for biological quality elements was 'Moderate', due to sea grass beds at the entrance to the Estuary (**Figure 2**) not being in favourable condition (which may be partly due to excess nitrogen and eutrophication). At the same time, phytoplankton and macroalgae (seaweeds) were classified at achieving 'Good' ecological status, which may be due to rapid flushing of nutrients out to sea and/or high levels of turbidity which reduce light availability for photosynthesis in the water column.

Additional Ground Water Safeguard Zones in the Exe catchment, which are at risk from nitrate fertilzers (and possibly pesticides) include the following:

GWSGZ 0063	Colaton Raleigh 2 & 4	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/ccb2ef54792f419690c5b84026965d9b/data
GWSGZ 0064	Dotton Boreholes 1-5,7	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/27f42f1c454740e4bae4586acd084d31/data
GWSGZ 0066	Starcross	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/83a4e5b53208425b9b6e19367a5154c5/data
GWSGZ 0069	Greatwell Borehole 1, 2 , 3, 4b, 6p	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/363ec486fe444376afc10b646dab970c/data
GWSGZ 0070	Harpford	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/cf22d6c611664f77812ed533257424bc/data
GWSGZ 0071	Otterton Bh4	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/c5ba3cc908674d41a691e7f047959484/data
GWSGZ 0072	Starcross	https://environment.data.gov.uk/portalstg/sharing/rest/content/items/0ce89a7f5c4b4f80b46b42f483b8773b/data

5 Water quality pressures and solutions (remedial measures)

Principal sources of water pollution in the Exe Estuary catchment include agricultural discharges (largely diffuse agricultural runoff from farm land), point source municipal waste water discharges, and industrial discharges, which may be point source or diffuse, e.g. in the case of abandoned copper and silver mines on Exmoor. The scale and likely influence of each of these sources on water quality in the Exe Estuary catchment are investigated in detail below.

As an overview, Environment Agency investigations into reasons for not achieving 'Good' ecological status under the Water Framework Directive found that diffuse pollution from agricultural sources accounted for 54% of failures for water bodies in the East Devon catchment (including the Exe Estuary catchment). East Devon Catchment Partnership also report that water quality problems are more often related to manure and slurry runoff from farming compared to municipal sewage inputs and runoff from urban areas (East Devon Catchment Partnership, 2021).

The proportional contribution of different sources of pollution vary depending on location and the pollutant concerned. For this reason, the sources and solutions for different pollutant classes in the Exe Estuary catchment are investigated and discussed separately below.

Under flood conditions pollution sources can merge and therefore integrated solutions involving wider catchment planning e.g. combining land and sewer system management are often called for. These integrated pressures and solutions for managing water quality are discussed first.

5.1 Integrated pressures and solutions for managing water quality

The Government's 25 Year Environment Plan (25 YEP) identifies the need for a joined up approach, i.e. to integrate agricultural development, under the new UK Agriculture Bill, with the environmental management of land, air and water to enhance biodiversity and ecosystem functioning. Most importantly the 25 YEP aims to maximise the delivery of multiple ecosystem services from agricultural landscapes through implementation of holistic catchment-based approaches and natural capital-based Environmental Land Management Schemes (HM Government, 2018a; 2018b).

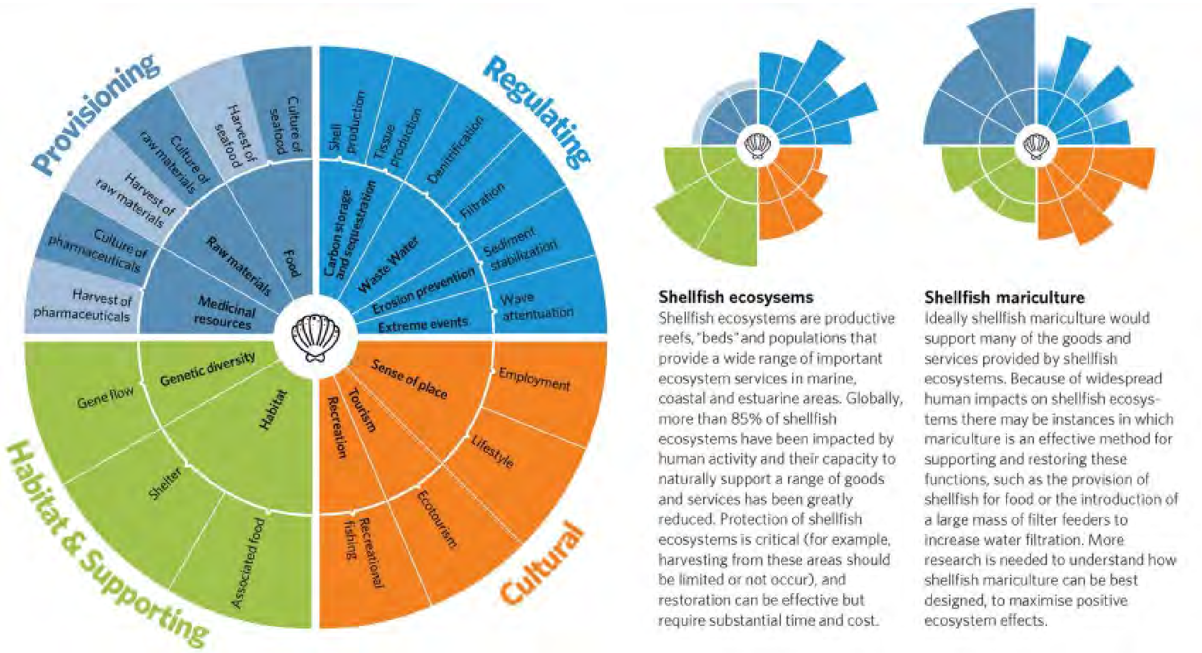
The East Devon Catchment Partnership advocate an ecosystem services approach in catchment management planning (West Country Rivers Trust, 2014). An integrated ecosystem services approach has been developed by Westcountry Rivers Trust to enable opportunity mapping in East Devon, including water quality (and quantity) regulation through natural flood management and Catchment Sensitive Farming. Management options include: i) restoring/maintaining good soil condition; ii) restoring/creating wetland habitats including Culm grasslands; iii) tree planting to increase rainfall interception and soil infiltration (Westcountry Rivers Trust, 2014). Examples of integrated catchment management in action include South West Water's Upstream Thinking Programme covering the Exe main and Creedy and West Exe catchments (SWW, 2021b), East Devon County Council's Clyst Valley Regional Park and Devon County Council's Connecting the Culm project (2019-2022).

The South Marine Planning policy S-WQ-1 also refers to the importance of ecosystem services in helping to regulate water quality. Habitats such as coastal saltmarsh, intertidal mudflats, seagrass, reed beds and natural blue mussel beds provide ecosystem services which maintain and can improve water quality. Policy S-WQ-2 encourages activities improving water quality including habitat restoration and bioremediation.

5.1.1 The role of shellfish and shellfish aquaculture in maintaining ecosystem functioning, including regulating water quality

Bivalve shellfish such as mussels and oysters play an important role in the healthy functioning of estuarine and marine ecosystems and the provision of ecosystem services (ES) that contribute to human wellbeing (**Figure 4**) (Theuerkauf et al., 2021). As filter feeders these shellfish help maintain water quality, by removing microbial and chemical contaminants (Smaal et al., 2019). By forming biological reefs, shellfish also help regulate coastal wave action and sediment dynamics and provide biodiverse habitats in an otherwise sediment-dominated environment (Seed and Suchanek, 1992; Andrews et al., 2011; Theuerkauf et al. 2021). For example "blue mussel beds on sediment" are listed as a UK Biodiversity Action Plan (BAP) Priority Habitat (JNCC, 2011). Bivalve shellfish also constitute an important food source for predatory invertebrates (crabs and lobsters) and vertebrates (fish, mammals and birds), as well as for humans (JNCC, 2011).

Figure 4: Ecosystem service provisioning by natural shellfish ecosystems and farmed shellfish (mariculture) – Figure by Alleway et al. (2018)



Delivery of ecosystem services is often highly variable, both spatially and temporally, depending on the condition of the ecosystems providing them (Maes et al., 2020), on hydrodynamic conditions which vary greatly along estuaries and coasts, and also on service accessibility/perceptibility by humans (Grabowski et al., 2012; La Peyre et al., 2014; Theuerkauf et al., 2021). Additionally, interactions occur between the different ecosystem services, which in turn influence the goods and benefits derived. These interactions can operate through trade-offs, i.e. one ecosystem service or benefit can have a negative impact on another.

The use of bivalve shellfish to bio-remediate water quality (microbial, chemical, nutrient and turbidity related water quality) in the Exe Estuary has been examined by the Marine Management Organisation - Project No: 1105 on Environmental remediation in South Marine Plan Areas (**Appendix 10**). The 'bottom cultivation' (on the estuary bed) of native oysters (*Ostrea edulis*) and blue mussels (*Mytilus* *edulis*) was rated as most cost-effective, with native oyster cultivation scoring highest for sustainability, and equal with mussels for additional environmental and societal benefits (e.g. provision of reef-forming habitat, fish nursery function and waste removal) (Marine Management Organisation, 2016). Bivalve shellfish could reduce nitrogen in water bodies by between 1 – 15 % of annual loads and occasionally up to 25 % of daily loads (Marine Management Organisation, 2016).

6 Faecal pollution

Environment Agency bathing waters investigations using a DNA tracing technique suggest the majority of faecal indicator bacteria are of ruminant origin at Exmouth Town Beach (CEFAS, 2013). Exmouth bathing water is affected by the catchment surrounding the Littleham Brook (600 ha), and by the Exe Estuary catchment (~150,000 ha), which contain over 50 dairy and other livestock farms (HM Government 2021a). Faecal matter from grazing livestock is either deposited directly on pastures, or collected from livestock sheds, if animals are housed indoors during the colder months, and then applied to agricultural lands as a fertilizer. Significant numbers of poultry and some pigs are also farmed in the catchment. Manure from pigs and poultry is typically stored without containment and applied tactically to nearby farmland.

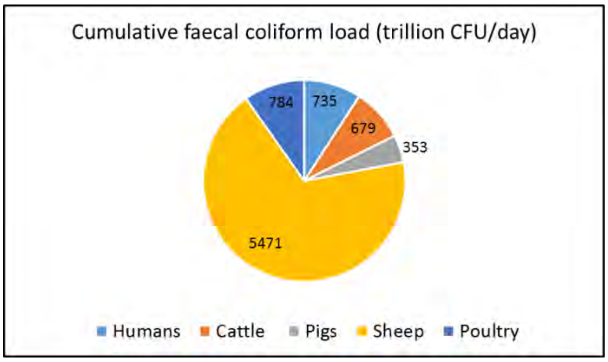
Simple calculations based on livestock numbers and human population numbers in the Exe Estuary catchment support these water quality monitoring investigations i.e. confirming that faecal production is likely to be dominated by livestock. Sheep carry the highest faecal coliform load per gram of faeces and multiplying this value by the total amount of faeces per individual and the number of individuals yields the highest contribution to the total faecal coliform load (68%) (**Table 9; Figure 5**).

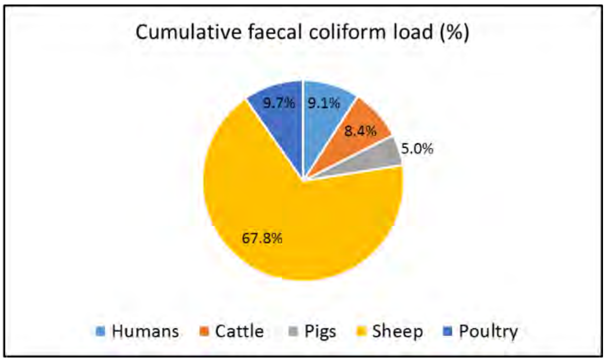
Table 9: Calculated daily faeces and faecal coliform production from humans and livestock in the Exe Estuary catchment

CFU is colony forming unit for faecal coliform bacteria. Data: a) CEFAS (2013); b) AgCensus (2010).

Source	a) Faeces per individual per day (g [wet weight])	a) Faecal coliforms (million CFU/g faeces [wet wt])	Faecal coliforms per individual per day (million CFU/indiv/day)	a), b) Population number in Exe Estuary catchment	Cumulative faecal coliform load (trillion CFU/day)	Cumulative faecal coliform load (%)
Humans	150	13.0	1950	377000	735	9.1
Cattle	23600	0.23	5428	125045	679	8.4
Pigs	2700	3.3	8910	45166.7	353	5.0
Sheep	1130	16.0	18080	302595	5471	67.8
Poultry	182	1.3	236.6	3315432	784	9.7

Figure 5: Calculated daily faeces and faecal coliform production from humans and livestock in the Exe Estuary catchment





Investigations concerning faecal pollution highlight increasing trends throughout the UK (House of Commons Environmental Audit Committee, 2022), including SW England and the Exe Estuary catchment (River Trusts, 2021). These investigations also highlight the importance of flood events in increasing sewer overflows and land run-off. Climate change is bringing increasingly wet winters to the UK (Kendon et al., 2021). For example February 2020 was the UK's wettest February since records began in 1862; mean total rainfall was 209 mm (237% of the long-term average).

Potential sources and hotspots concerning faecal pollution in the Exe Estuary's and Lyme Bay's shellfish waters have been investigated via systematic sanitary surveys comprising walk-over surveys and desktop studies (CEFAS, 2013; CEFAS, 2015; Carcinus, 2021). **A key conclusion from these sanitary surveys is that shellfish production areas, which are most at risk from faecal contamination lie in the upper Exe Estuary around the confluence of the Exe at Countess Wear and the confluence of the Clyst at Topsham, and also in the mid estuary, at the confluence of the River Kenn** (Carcinus, 2021).

6.1 Municipal sewage inputs

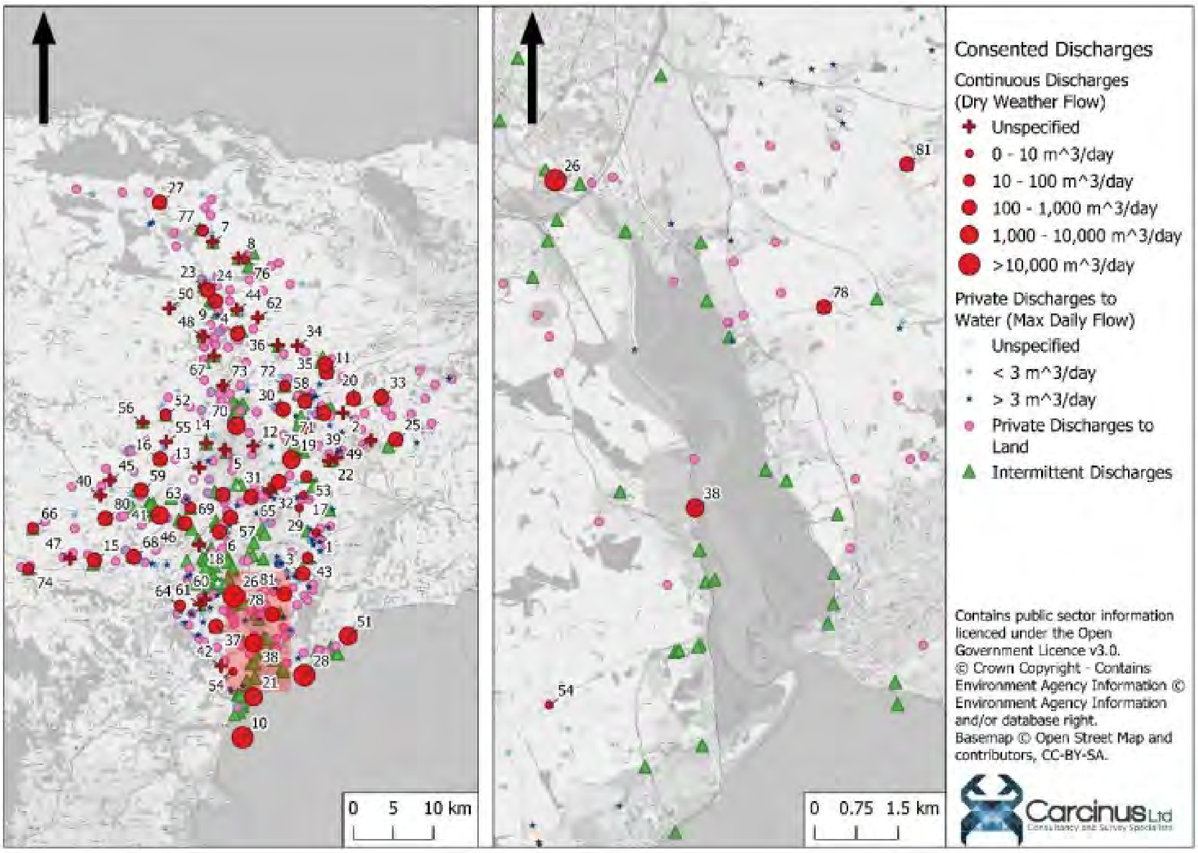
There are 82 consented continuous sewage discharges within the Exe Estuary catchment and Exe Estuary, which receive various physical, chemical and biological treatments (**Figure 6; Appendix 11**). Total waste water treatment works (WWTW) discharges amount to ~70,000 m^3/day, which is equivalent to 0.8 m^3/sec (3.2% of mean river flow, i.e. 25 m^3/sec for the River Exe at Trews Weir) (SWW; UK CEH, 2021). Exeter's Countess Wear WWTW has the highest permitted dry weather flow of 40,486 m^3/day (UV treated), making up over half the total of all continuous discharges in the Exe main catchment. The second and third highest continuous sewage discharges in the Exe Estuary catchment are from Exmouth (11,825 m^3/day) and Dawlish sewage treatment works (4,856 m^3/day), respectively – both are UV treated and discharge into Lyme West via long sea outfalls to protect coastal bathing waters. Other significant continuous discharges to Lyme Bay West include Teignmouth's Buckland STW (21,818 m^3/day), which is not UV treated, but discharges via a long sea outfall. Other significant continuous discharges to the shellfish waters of the Exe Estuary include Kenton and Starcross (1,750 m^3/day; UV treated) and Woodbury sewage treatment works (408 m^3/day; not UV treated) (**Appendix 11**).

There are 251 consented intermittent discharges within the Exe Estuary catchment, of which 50 are within 2 km of the Exe estuary. Intermittent discharges comprise Combined Sewer Overflows (CSOs), Storm Tank Overflows (STOs), Sanitary Sewer Overflows (SSOs) and pumping station emergency overflows, all of which can result in the release of untreated sewage into surface waters (Carcinus, 2020) (Figure 6; Appendix 12). Exeter's Countess Wear SSO is the single largest intermittent discharge, which, before the installation of UV treatment in 2018, contributed 42.6% (2.6 $\times 10^{11}$ *E. coli* CFU) of the total bacterial load (6.1 $\times 10^{11}$ *E. coli* CFU) from all intermittent discharges into the Exe

Estuary (Pateman et al., 2018). Spill frequencies and durations of intermittent discharges into the Exe Estuary and Lyme Bay West for 2020 are taken from The Rivers Trust https://www.theriverstrust.org/key-issues/sewage-in-rivers and are summarised in **Appendix 13**. Among the 36 intermittent discharges identified, 26 exceeded their spill frequency trigger permit in 2020 (spills per year as 10 year averages: 40 spills for water bodies; 14 spills for shellfish waters; 5 spills for bathing waters - per bathing season) (SWW, 2021a). Of these 15 have been highlighted for further investigation and improvement. The most frequent and longest duration intermittent discharges are Maer Road CSO entering Lyme Bay at Exmouth (65 overflows, 858 hrs), Warren Road CSO entering Shutterton Brook and the Exe Estuary at Dawlish; Cofton CSO entering Cofton Stream and Cockwood Harbour (45 overflows, 384 hrs); Bonhay Road CSO, entering Exe Estuary at Starcross (20 overflows, 129 hrs); Exton North entering the River Clyst and Exe the Estuary (146 overflows, 2003 hrs).

In addition to the water company owned discharges, there are a number of privately owned (STW and septic tank) discharges within the catchment. Few of these discharge directly to water bodies near the shellfish classification zones; the most significant include private STWs serving Haldon Forest Holiday Park (45 m^3 day^{-1}) and the Lord Haldon Country Hotel and Haldon House at Dunchideock (27 m^3 day^{-1}), both of which discharge into the River Kenn (Environment Agency, 2018a, 2018b; Carcinus, 2021).

Figure 6: Consented continuous and intermittent sewage discharges contained within the Exe Estuary catchment, Exe Estuary and Lyme Bay West – See Appendix 11 and 12 for further details.



6.2 Faecal pollution from agriculture

Faecal pollution from agriculture potentially originates from two main sources, the application of sewage sludge (biosolids) and the application of livestock manure/slurry to fertilise arable land for crops and improved grassland for livestock grazing.

6.2.1 Sewage sludge

Sewage sludge is a by-product of the treatment of sewage. In 2020/21 South West Water produced 42.85 thousand tonnes of dry solids (from sewage sludge) and of this 42.72 were recycled or disposed via their bioresources service, with the majority being subjected to anaerobic digestion and lime stabilisation techniques to create a biosolid product for agricultural use (SWW, 2022). Anaerobic digestion (AD) is being used increasingly in developed countries for treating sewage sludge, with the principle aims of volume reduction and biogas production, the latter being used for energy generation. Pathogen removal is also a key aim, if the biosolids produced by AD are to be used to fertilise pasture or arable land, so as to safeguard agricultural crops, livestock and human consumers. Once optimised AD has been shown to deactivate a wide range of pathogens, including bacteria, parasites, viruses and other microbes harbouring antibiotic resistant genes (ARGs). Monitoring is needed to establish quantitative relationships between commonly used faecal indicators such as *E. coli* and AD resistant-pathogens and to track ARGs in AD resistant microbial hosts (Zhao and Liu, 2019). The presence and sources of antibiotics and ARGs in the Exe Estuary catchment are discussed in **Section 11**.

6.2.2 Farmyard manure and slurry

Manure applied to agricultural land is produced by livestock as farmyard manure (FYM), diluted slurries, and poultry manures, which all largely remain in their natural form. Manures are by far the largest components of organic fertilisers used in agriculture in England; others include anaerobically digested (AD) sewage sludge (bio-solids) and some industrial 'wastes' such as compost, paper waste or brewery effluent (**Table 10**) (DEFRA, 2021c).

Since farmyard manures and slurries are untreated, they are also the primary source of pathogens in 'farm to fork' microbial risk assessments. Recent research has shown that the prevalence of a range of pathogens in farmyard manure and slurry varies substantially between countries, depending on temperature, storage, livestock sources and levels of livestock vaccination (**Appendix 14**). Nevertheless, even in developed countries such as Ireland, the prevalence of *Cryptosporidium* spp. in cattle may be as high as 26% (Nag et al., 2021).

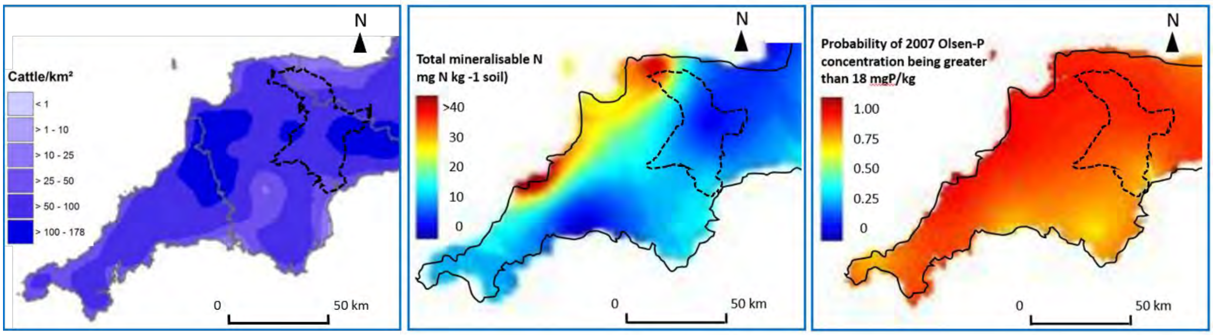
Table 10: Proportion of overall organic application rates per hectare of farmed area (excluding rough grazing) by nutrient type, England 2019/20

(a) Includes home produce, imported and purchased FYM and Slurry

Source of organic fertiliser	**Nutrient provision**		
	Nitrogen	**Phosphate**	**Potash**
Farmyard manure (FYM) & slurry[(a)]	89%	84%	95%
Digestate from on-farm anaerobic digestion	<1%	<1%	<1%
Digestate from off-farm anaerobic digestion	7%	2%	2%
Other organic products	4%	14%	3%

No spatial data were found to be available for faecal inputs from manure and slurry. Inputs can potentially be inferred from the density of livestock grazing and variation in soil fertility with respect to total mineralisable nitrogen and Olsen-P as a measure of the fertility of agricultural soils across the Exe Estuary catchment is shown in **Figure 7**. Cattle grazing density distributions (dairy and beef cattle) were obtained from the Animal and Plant Health Agency (APHA, 2020). Total mineralisable-N and Olsen-P distributions were obtained from the Countryside Survey Soils report (UK CEH, 2010). The plotted data indicate that manure and slurry inputs are more likely the mid to lower Exe Estuary catchment, particularly in the Culm. Traditionally the Culm area has been grazed extensively by cattle and sheep. Since the outbreak of Foot and Mouth disease in 2001 livestock are less evenly distributed across the Culm and livestock now graze in more concentrated groups (Devon Wildlife Trust, 2014).

Figure 7: Variation in livestock grazing and in soil fertility (as indicators of manure and ferliser spreading) across the Exe Estuary catchment



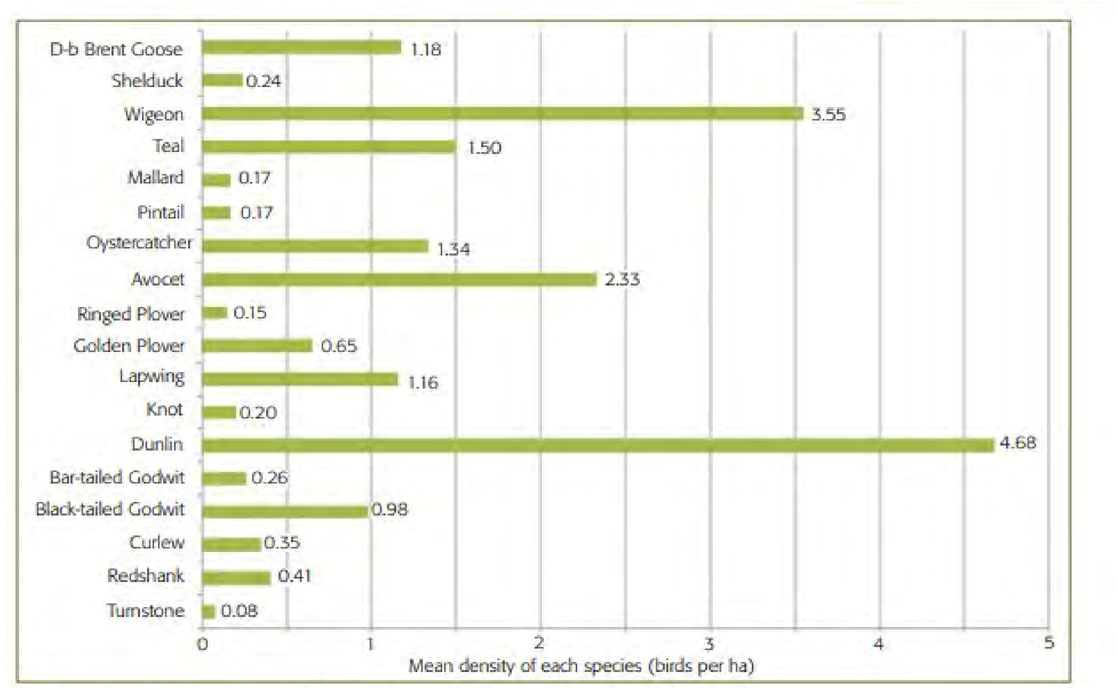
6.3 Faecal pollution from boats and shipping

A variety of boats navigate Lyme Bay and the Exe Estuary and potentially make overboard sewage discharges in the designated shellfish and bathing waters. There are around 1,800 moorings in the Exe estuary alone (CEFAS, 2013). Significant fishing fleets of <100 boats operate from Exmouth and Brixham; an additional 20 fishing vessels are listed as having their home port at Beer, Sidmouth or Axmouth (Carcinus, 2021). Fishing vessels have been observed to operate in areas adjacent to the offshore mussel farm (Lyme Bay Sites 1 and 2), and vessels using static gear may well operate within the lease boundaries. Theses fishing vessels potentially make overboard discharges in close proximity to the mussel lines from time to time, and their presence is likely to be evenly distributed throughout the year. Larger vessels, such as tankers and container ships also regularly pass through Lyme Bay, although the main shipping routes are located in the central English Channel and ships are not permitted to make overboard discharges within 5.5 km of land (Carcinus, 2021).

6.4 Faecal pollution from wildlife

Marine wildlife populations including water birds and marine mammals are a potential source of faecal contamination to shellfish and bathing waters. There are no major seal colonies in Lyme Bay or the Exe Estuary, however, they are spotted frequently in coastal waters, as are harbour porpoises and several dolphin species (Carcinus, 2021). Water birds, including wading birds and waterfowl are abundant in the Exe estuary, and populations regularly swell with the arrival of overwintering migrants. Annual water bird numbers averaged over the period 2015-2020 are 22,533 birds according to the BTO Wetland Bird Survey (WeBS) (Frost et al., 2021). The relative densities of different species of water birds in the Exe Estuary in 2016 are presented in **Figure 8**. These various water birds roost mainly in marginal wetlands, including Exminster and Bowling Green marshes and also on Dawlish Warren (Knot, 2021). Water birds may in the winter contribute to the loadings of faecal indicator organisms to estuarine and coastal shellfish waters (and bathing waters) on ebbing spring tides, following tidal inundation of the marshes. This represents a moderate risk (CEFAS, 2013; Carcinus, 2021). It is important to note that microbial communities, including faecal coliforms and pathogens (e.g. *Clostridium, Campylobacter* and *Helicobacter*) can vary substantially between wading bird species (Keeler and Huff, 2009) and these microbial communities also differ substantially to those associated with human and agricultural livestock faeces (Boukerb et al., 2021). Further work is required to better understand these variations in order to improve the tracking of faecal pollution sources in catchments.

Figure 8: Relative densities of different species of water birds in the Exe Estuary in 2016



▲ **Mean densities of waterbirds at low tide on Exe Estuary in 2016/17.**

Simple calculations based on water bird numbers in the Exe Estuary indicate that faecal coliform production is likely to be dominated by wildfowl, including Brent goose, Shelduck, Widgeon, Teal, and Mallard ducks (62%). Wading birds, including Bar-tailed and Black-tailed godwit, Oystercatcher, Avocet, Knot, Dunlin and Lapwing are also substantial contributors to faecal coliform production by waterbirds (37.9%), while gulls are likely to be minor contributors (0.1%) (**Table 11; Figure 9**).

Table 11: Calculated faecal coliform production from wading and water birds in the Exe Estuary in 2016/17

Data sources: a) Jones and Obiri-Danso (1999); b) Meerburg et al. (2011); c) Scherer *et al. (1995); d) Frost (2018). Less abundant water bird species are not accounted for in this table (e.g. egrets, rails).*

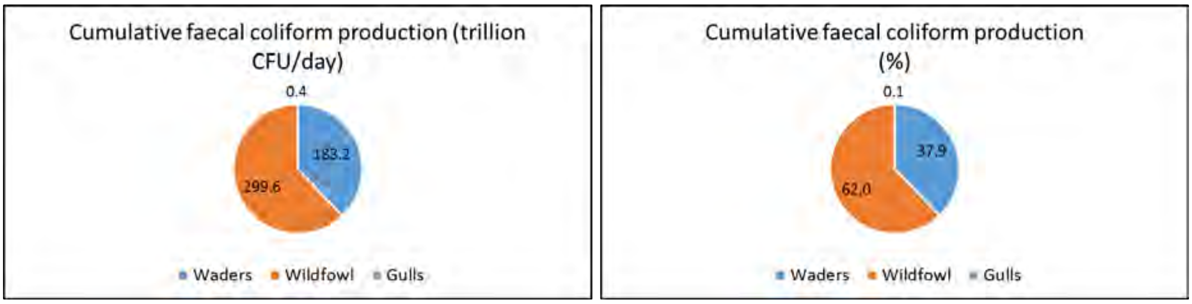
CFU is colony forming unit for faecal coliform bacteria.

Table 11: Calculated faecal coliform production from wading and water birds in the Exe Estuary in 2016/17

Data sources: a) Jones and Obiri-Danso (1999); b) Meerburg et al. (2011); c) Scherer *et al. (1995); d) Frost (2018). Less abundant water bird species are not accounted for in this table (e.g. egrets, rails). CFU is colony forming unit for faecal coliform bacteria.*

Water bird	a), b) Average abundance of faecal coliforms (million CFU/g of faeces wet weight)	c) Estimated faecal production (g/ bird/ day)	Estimated production of faecal coliforms (million CFU /24h /bird)	d) Mean annual total birds	Cumulative faecal coliform production (trillion CFU/day)
Bar-tailed and Black-tailed godwit	7080	10	7080000	873	61.8
Oystercatcher and Avocet	4700	10	4700000	2584	121.4
Knot	0.529	5	2.645	141	0.0004
Dunlin	0.529	5	2.645	3295	0.0087
Lapwing	0.255	8	2.040	817	0.0016
Waders				7709	183.2
Shelduck and Widgeon	736	18	13248	2668	35.3
Mallard	78300	27	2114100	120	253.0
Teal	736	13	9568	1056	10.1
Brent Goose	8.8	160	1408	831	1.2
Wildfowl				4675	299.6
Gulls	17.5	15	262.5	1408	0.3696

Figure 9: Calculated faecal coliform production from water birds in the Exe Estuary in 2016/17



6.5 Solutions addressing faecal pollution

6.5.1 Reduction and treatment of raw sewage discharges

Under the freedom of information act, data showing frequent spills of raw sewage from UK water company-owned intermittent discharges to watercourses in the UK in 2019 and 2020 (reaching ~400,000 spills in 2020) are now publically available https://www.theriverstrust.org/key-issues/sewage-in-rivers. These data, and pressure from the Environmental Audit Committee and the House of Lords prompted HM Government to make provisions in the Environment Act (2021) to set long-term statutory targets for the improvement of the natural environment, including for water companies in England to secure progressive reduction in the adverse impacts on the environment and on public health of discharges from storm overflows. Ministers are also required to publish, by September 2022, a plan to reduce sewage discharges from sewer overflows and their adverse impacts, including on public health https://www.legislation.gov.uk/ukpga/2021/30/contents/enacted.

Improvements in sewage systems are currently made through the Water Industry National Environment Programme (WINEP), the programme of work water companies in England (and Wales) are required to do to meet their obligations from environmental legislation and UK government policy (HM Government, 2021b). WINEP is delivered through implementation of Asset Management Plans (AMPs) agreed between each of the regional water companies and the Environment Agency.

With regard to continuous discharges, South West Water (under AMP6: 2015-2020) invested in construction of new sewage treatment works (STWs) (£2.532 million) and expansion of existing STWs (£3.723 million), with additional investment in nutrient (phosphate) removal by activated bed STWs (£4.255 million) and filter bed STWs (£4.144 million) (Expenditure for 2020 – SWW, 2020). Recent, notable upgrades in 2021 to continuous discharges in the vicinity of the Exe Estuary include the deployment of UV disinfection at the Kenn and Kennford STW (Carcinus, 2021).

With regard to intermittent discharges, a systematic approach is used by water companies (including SWW) to prioritise infrastructure improvements, which will improve the quality of protected shellfish waters and bathing waters – the approach taken follows Urban Pollution Management (Foundation for Water Research, 2019) and employs the Storm Overflow Assessment Framework (SOAF) (**Appendix 14**). Overflows are counted using Event Duration Monitoring (EDM) and targeted for investigation if they exceed a spill frequency trigger permit (spills per year as 10 year averages: 40 spills for water bodies; 14 spills for shellfish waters; 5 spills for bathing waters - per bathing season) (SWW, 2021a). After checking rainfall data for exceptional rainfall events, for which overflows are permitted, investigations are made into possible sewer blockages or leaks and whether the hydraulic capacity of the system is adequate. Then the environmental and aesthetic impacts of the intermittent discharge are determined and used to identify the most cost beneficial solution to reduce the impact and/or frequency of discharges.

To protect shellfish water quality in the Exe Estuary, South West Water made improvements to eleven CSOs within the Countess Wear STW (Exeter) sewerage catchment by March 2018. Based on SOAF cost-benefit assessments and investments under AMP6 (2015-2020), improvements were prioritised for the Countess Wear sanitary sewer overflow (SSO). This SSO was considered the single largest intermittent discharge impacting on the quality of shellfish waters and bathing waters of the Exe Estuary and adjoining coast (Pateman et al., 2018). Improvements introduced UV disinfection, which was predicted to remove 42.6% of the total average annual bacterial load from all intermittent discharges in the catchment (including STOs, SSOs and CSOs) (**Table 12**). The aim was to achieve $\leq$ 300 *E. coli* /100 mL in shellfish flesh and intravalvular fluid, in compliance with the Shellfish Water Protected Areas (England and Wales) Directions 2016 (HM Government, 2016) (Pateman et al., 2018). However, no *E. coli* monitoring data are currently available for Countess Wier SSO, so its impact on shellfish waters in the Exe Estuary cannot be assessed directly. Currently the closest representative monitoring point for shellfish (Cockwood Harbour) is approximately 9.5 km downstream. Another notable AMP6 improvement project benefiting the Exe Estuary targeted Lympstone outfall pumping station. The project incorporated infiltration removal and storm water storage to achieve a reduction in CSO spills (to less than 10 significant spills per annum) and screening to improve spill quality (Steer et al., 2018).

A further nine CSOs were scheduled for improvements by SWW by June 2021. Information on these improvement projects was not available for this report.

Table 12: Summary of bacterial loads (*E. coli* cfu – colony forming units) and estimated reductions due to Countess Wear SSO disinfection

Intermittent discharges in the Exe Estuary catchment entering the Exe Estuary	Estimated load m^3 x *E. coli* cfu/100ml	Estimated load (%)
Total contribution from CW storm tank discharges	2.6×10^{11}	42.6
Total contributions from other intermittent discharges	3.5×10^{11}	57.4
Total estimated load from intermittent discharges	6.1×10^{11}	100

6.5.2 Sustainable Urban Drainage Systems

As part of its "Downstream Thinking" Programme, South West Water is running an on-going WaterShed Project in Exmouth to store water in tanks, to manage/recycle rainwater for domestic use, and to build Sustainable Urban Drainage Systems (SUDs) including rain gardens that will hold water during storms before slowly soaking into the ground or feeding gradually back into the sewerage network. The WaterShed project is expected to reduce combined sewer overflows into the Exe Estuary (SWW, 2021c).

6.5.3 Management of farmyard manures and slurries

Given the potentially high pathogen load in farmyard manures and slurries (**Appendix 14**), managing their storage and agricultural use as organic fertilisers is highly important for food safety, particularly in the case of ready to eat crops (salads, fruits and vegetables). Guidelines provided by the Food Standards Agency (2009) should be followed to minimise the risk of microbial pathogen contamination. These guidelines include:

- You should NOT apply fresh solid manure or slurry (i.e. manure that has not been batch stored or treated e.g. with lime) within 12 months of harvesting a ready-to-eat crop, including a minimum period of 6 months between the manure application and drilling/planting of the crop.
- You should also ensure that there is a 12 months gap between livestock last grazing in the field and harvesting of a ready-to-eat crop, including a minimum period of 6 months between the last grazing and drilling/planting of the crop.
- Spreading of treated or batch stored solid manure or slurry (stored for at least 6 months) should take place before drilling/planting of the crop.

Additional prioritised interventions highlighted in the DEFRA funded Demonstration Test Catchment project (WQ0203) in the Tamar SW England by Crowther et al. (2018) and Kay et al. (2018) for reducing diffuse faecal/microbial pollution from agricultural sources to coastal waters include:

- Containing manures and slurries before application to land and minimising yard runoff from farm steadings
- Managing intensively grazed (particularly streamside) pastures by installing stream bank fencing and water troughs can reduce mean *E. coli* and intestinal enterococci inputs to water courses by $\log_{10}$ 0.842 and 2.206, respectively
- Creating Free Water Surface Constructed Wetlands can reduce *E. coli* inputs by $\log_{10}$ 1.88, while dirty water treatment systems can reduce *E. coli* inputs by $\log_{10}$ 1.34-2.92
- Minimising runoff and slowing water flows by constructing riparian vegetated buffer strips and creating grass swales along ditches.

- Modelling FIO attenuation along watercourses e.g. $\log_{10}$ 1.0 die-off for *E. coli* may occur within 3 – 50 hrs depending on sunlight intensity and water turbidity (Figure
- Prioritising pollutant sources located closest to the coast.

6.5.4 Catchment management

Schemes benefiting water quality by reducing agricultural runoff and faecal pollution in the Exe Estuary catchment include:

- Countryside Stewardship, including Catchment Sensitive Farming (CSF) – A major attribute of CSF is the monitoring of environmental improvements following advice and interventions on farming practice across priority areas, including those in SW England (**Appendix 16**). To date, a total of 127 different CSF measures have been advised on farm infrastructure, livestock and manure management, land use and soil management, pesticide and fertiliser management. Farm infrastructure, livestock and manure management measures have contributed to -91% FIO reductions (Natural England, 2019).
- The introduction of CSF Farming Rules for Water (The Reduction and Prevention of Agricultural Diffuse Pollution (England) Regulations 2018) – These rules require reasonable precautions to ensure that manure and fertiliser applications do not 'exceed the needs of the soil and crop on that land' or 'give rise to a significant risk of agricultural diffuse pollution'. Rules for arable land include establishing crops early in the autumn months, and during dry conditions; planting headland rows and beds across the base of any sloping land; under-sowing or sowing a cover crop to stabilise soil after harvest; removing compacted soil; establishing grass (buffer) strips in valleys, or along contours or slopes, or gateways. For managing livestock precautionary measures include: moving livestock regularly; erecting fencing around controlled waters; wintering livestock on well-drained, level fields (DEFRA, 2018b).
- South West Water's "Upstream Thinking" programme - By 2050, SWW intends to implement catchment management for over 80% of their catchments, to improve raw drinking water quality and to restore landscapes for Biodiversity Net Gain (SSW, 2018).

7 Pesticide pollution

7.1 Sources

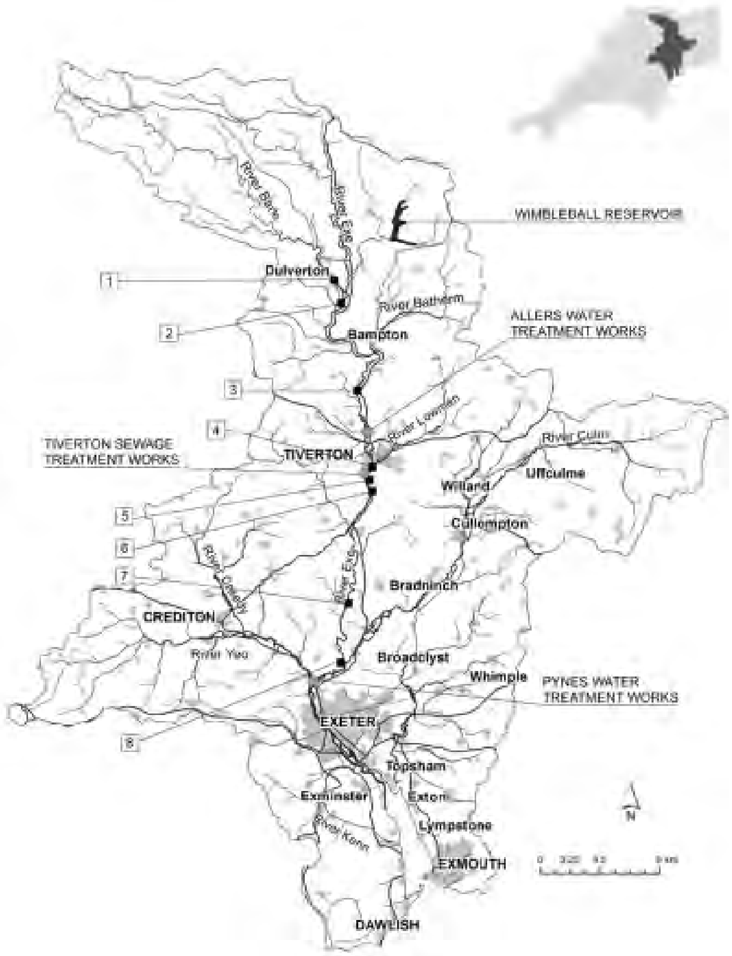
Pesticides, particularly herbicides are used in large quantities on agricultural land within South West England catchments (**Appendix 17**).

There is evidence of pesticide pollution in the Exe main operational catchment. South West Water's raw water monitoring data for Allers and Pynes Water Treatment Works show that some pesticides are detectable in the middle and lower reaches of the River Exe for most of the year (**Appendix 9**). The acid herbicides MCPA, mecoprop and triclopyr plus chlorotoluron and the slug treatment metaldehyde have been among the most frequently detected pesticides at the intake for Pynes WTW in the period 2008-2013, indicating both grassland and arable sources. During the 2008-2013 period detections of individual compounds increased and in particular the maximum concentration of MCPA exceeded the 0.1 μg/L standard in 2009 (SWW).

The East Devon Rural Diffuse Pollution Project commissioned by the East Devon Catchment Partnership identified 50 farms across the East Devon catchments of the Clyst (and also the Otter and Axe) with high risk of causing diffuse water pollution (Brown, 2018). 44 farms were growing maize in large fields prone to runoff due to sloping land, and either slowly permeable, compacted and/or eroding soils. 27 farms were investigated and all showed high runoff during heavy rain events, and 5 farms had a serious impacts on watercourses (defined by the EA as Category 2 water incidents). A detailed analysis was also carried out using soil maps provided by Cranfield University and showed that: >93% of the land used was at high risk of run-off; <19% of the land used for maize production was (naturally) freely drained; 60% of land used for maize production was at risk of erosion; >50% of maize land had a high risk of slurry pollution (Brown, 2018). It is not clear at this stage how conditions may change under the adoption of the 'Farming Rules for Water' (The Reduction and Prevention of Agricultural Diffuse Pollution (England) Regulations 2018).

To better understand the sources, transport and fate of acid herbicides in catchments SWW deployed calibrated Chemcatcher® passive samplers at eight strategically located monitoring stations along the river Exe from Dulverton to the intake of Pynes water treatment works in Exeter in May and June/July 2013 (**Figure 10**). These samplers captured time-weighted average concentrations (over 16 days) of 2,4-D, dicamba, dichlorprop, fluroxypyr, MCPA, MCPB, mecoprop, tricolpyr enabling the detection of diffuse pollution. 2. Based on both spot sampling and Chemcatcher® sampling, the concentrations of all herbicides were generally low (below the analytical limit of detection) in the upper catchment above Station 3 - Ironbridge (SS94261782) while concentrations of MCPA and mecoprop were elevated at Station 4 - the confluence of the River Lowman (SS95381200) and persisted to a lesser extent downstream. A significant pollution incident involving fluroxypyr (2.09 μg/L) and triclopyr (5.03 μg/L), a factor of 20 and 50 above the Drinking Water Directive limit of 0.1 μg/L was detected on one occasion by both spot sampling and Chemcatchers® in Jun/July 2013. The pollution incident was detected in Calverleigh Stream (SS93101452) close to the confluence with the River Exe, just below the intake to Allers WTW at Bolham Weir. Calverleigh Stream drains dairy pasture land treated periodically with acid herbicides. A spike in MCPA (0.17 μg/L) was also detected here by the Chemcatchers®, but this short-term pollution event involving MCPA was missed by sequential spot sampling (Townsend et al., 2018).

Figure 10: River Exe catchment showing the eight locations for the Chemcatcher® deployments



7.2 Solutions

Diffuse water pollution from agriculture in England and Wales is being addressed by the Department for Environment, Food and Rural Affairs' (Defra) Catchment-Sensitive Farming (CSF) as part of Countryside Stewardship. Farm infrastructure and pesticide management implemented through CSF have contributed to significant reductions in pesticide concentrations in rivers (-88%), including SW England (Natural England, 2019).

Reductions in pesticide pollution in the Exe Estuary catchment are being delivered through South West Water's Upstream Thinking programme, including the Headwaters of the Exe catchment and Exmoor Mires Projects (2015-2020). In these projects Devon Wildlife Trust and Westcountry Rivers Trust, in partnership with South West Water have provided advice on farm management and habitat regeneration (wooded slopes, wet grassland / marshland and farm ponds) to address pesticide (particularly acid herbicide) pressures on river ecology and drinking water quality in the Exe main catchment (SWW, 2021b).

Whole catchment-based risk assessment tools can help identify major pollution sources and target interventions. For example, an acid herbicide wash-off exploration tool has been developed at the University of Exeter with Westcountry Rivers Trust. This has been used to explore the potential impacts of acid herbicide wash-off (i.e. agricultural weed killer run-off from grassland) on water quality in relation to environmental quality standards (e.g. EQS short-term for mecoprop is 24 µg/L in freshwater and 1.7 µg/L in saltwater). These standards are designed to protect the most susceptible environmental species, in this case phytoplankton, which are the primary food source for wild and farmed bivalve shellfish. The tool has also been used to illustrate the benefits of different herbicide application and soil management strategies on river and estuarine water quality (Webber et al., 2021).

8 Nutrient enrichment

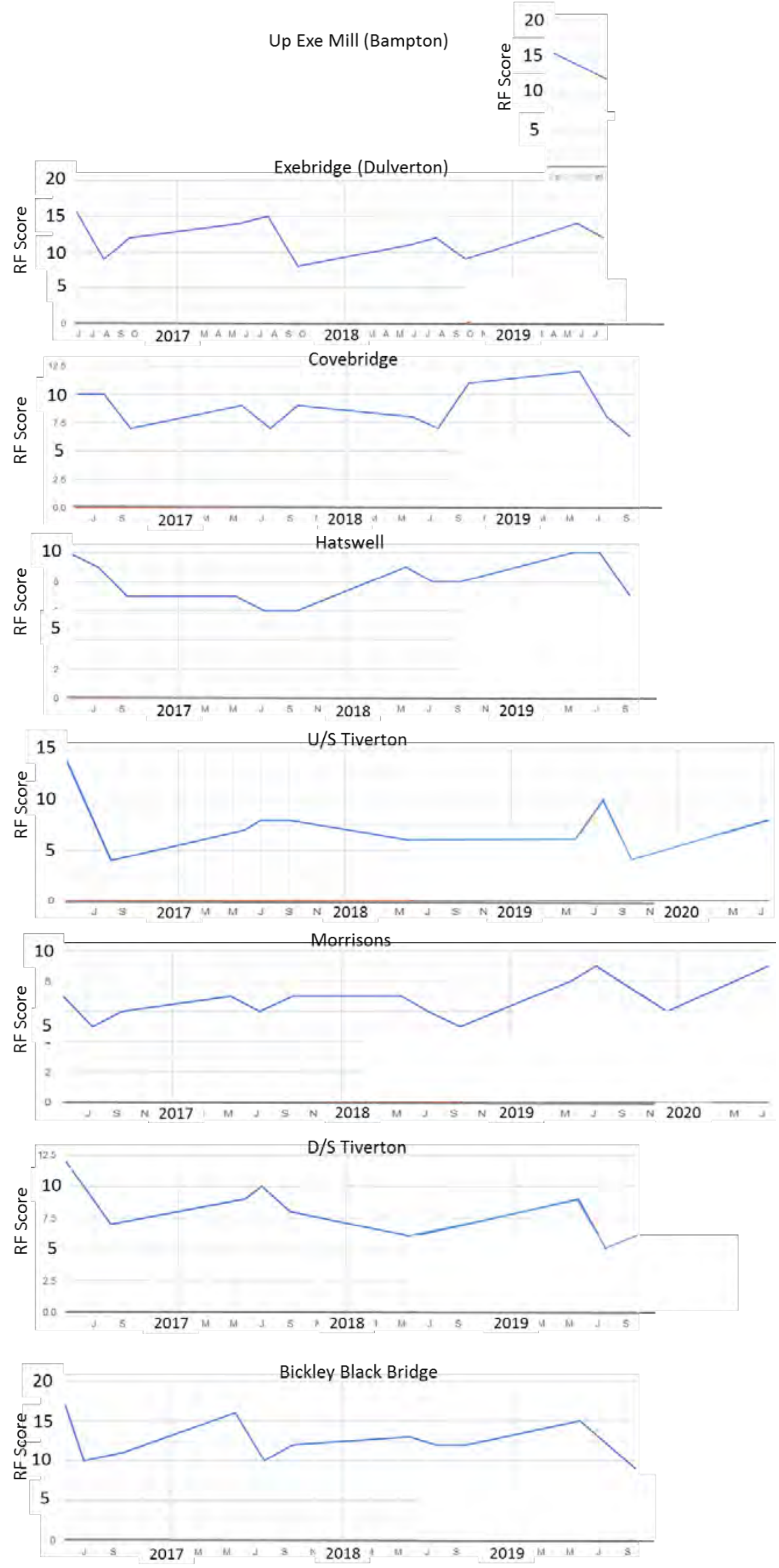
Nutrient enrichment includes inputs of macro-nutrients: carbon, nitrogen and/or phosphorus, each of which, in excess, can cause imbalances in river ecosystem structure and function. For example, excess carbon can lead to organic enrichment which can impact severely on aquatic invertebrate fauna diversity (Hawkes, 1998), while excess nitrogen (nitrate, nitrite, ammonium) and/or phosphorous (phosphate) can fuel algal blooms, which can smother habitats and cause oxygen depletion in the water column when blooms breakdown (a process called eutrophication). Algal blooms can also liberate metabolites which can cause tainting and odour issues in drinking water at low ng/l levels and act as a source of toxins such as microcystins (from blue-green algae).

8.1 Sources

8.1.1 Organic carbon

The Exe catchment is exposed to diffuse sources of organic enrichment from livestock grazing on improved and unimproved grassland. Point source sewage discharges may also lead to localised effects on water quality and on the biodiversity of aquatic invertebrates, with the loss of stonefly and caddisfly larvae being a sensitive indicator of organic enrichment (Hawkes, 1998). River invertebrate monitoring undertaken by the Riverfly Partnership https://www.riverflies.org/content/DataExplorer at eight stations spanning the upper Exe (Bampton) down to Bickleigh, below Tiverton shows typical seasonal variation in biodiversity (Riverfly (RF) score), with no noticeable inter-annual trends (2016-2020). There are also no strong indications of changes in biodiversity upstream and downstream of discharges from sewage treatment works, but there was a small reduction in the RF score in 2019 downstream of Tiverton (**Figure 11**).

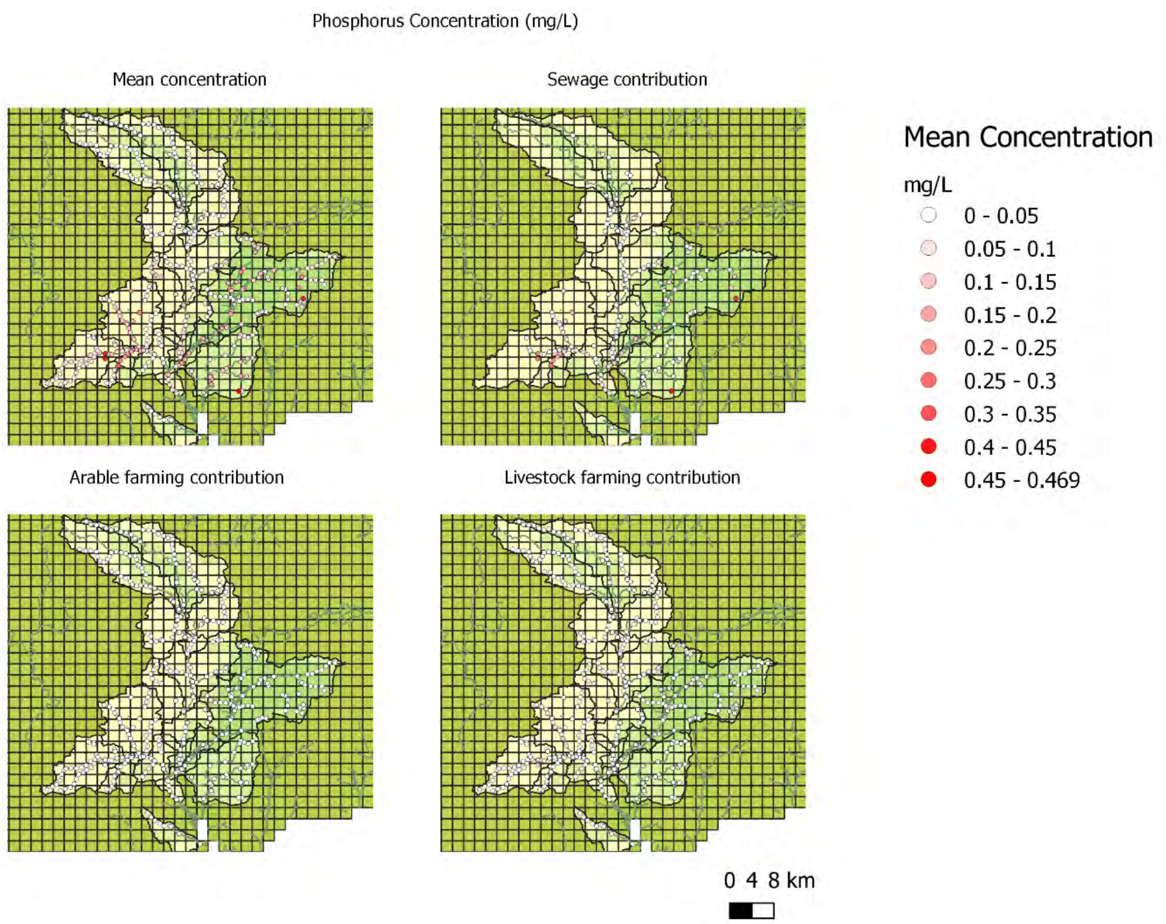
11: Variation in aquatic invertebrate biodiversity measured using the Riverfly (RF) score from the upper Exe (Bampton) down to Bickleigh, below Tiverton (2016-2020)



8.1.2 Phosphorous

Source Apportionment-GIS (SAGIS) modelling has been developed by UK Water Industry Research (UK-WIR) to identify and quantify sources of pollution (**Figure 12** – UK CEH 2021) (Comber et al, 2013). Source apportionment indicates that nutrient enrichment by phosphorous in the Exe catchment is caused mainly by point source sewage discharges (Westcountry Rivers Trust, 2014), with the prime sources being human excreta and domestic detergents (Comber et al., 2012). Urban and agricultural runoff are also significant sources of phosphorus in some parts of the Exe Estuary catchment, particularly in the Culm and the headwaters of the Creedy and West Exe One water body in the Creedy and West Exe (Holly Water – NGR SS8594207109) has persistently been classified as 'Poor' with respect to levels of phosphorous (measured as phosphate). Nine other water bodies in the Creedy and West Exe operational catchment were classified as 'Moderate' (i.e. not achieving the objective of 'Good') in 2019. Dissolved inorganic phosphorous is often associated with fuelling algal growth and eutrophication in rivers, leading to oxygen depletion in the water column. Only one water body - upper River Yeo (NGR SX7766198346) was classified as 'Moderate' in 2019 in terms of dissolved oxygen concentration (Environment Agency, 2021b).

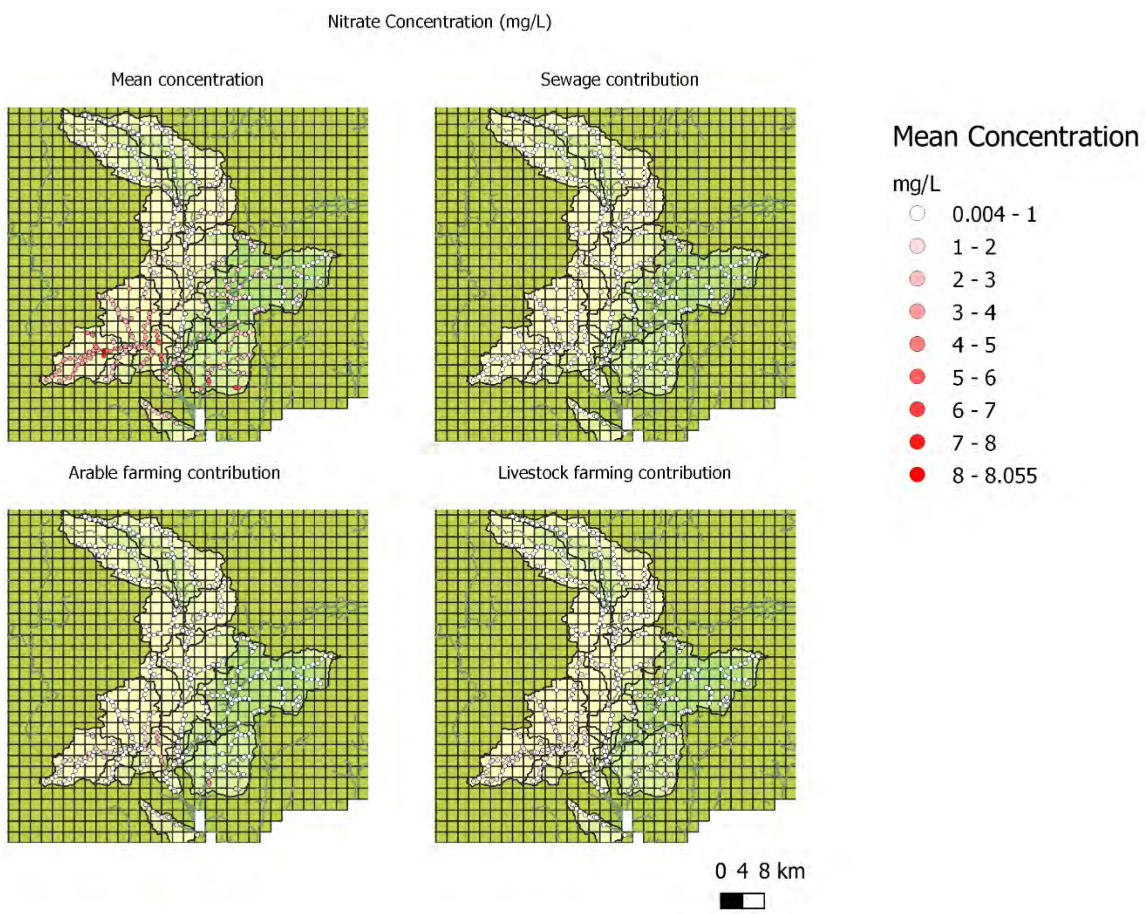
Figure 12: Source apportionment for phosphate in the Exe Estuary catchment



8.1.3 Nitrogen

Source Apportionment-GIS (SAGIS) modelling (**Figure 13** – UK CEH 2021) (Comber et al, 2013) indicates that nitrogen inputs are attributable more to diffuse agricultural runoff from arable land and improved grassland, following the use of nitrate-based fertilisers and livestock manure and slurry, which is rich in ammonia and ammonium. Dissolved inorganic nitrogen is more often associated with eutrophication in estuaries, i.e. excessive algal growth, which can significantly reduce dissolved oxygen concentrations when the biomass biodegrades. There is some historical evidence of algal blooms in the Exe Estuary, which have been linked to elevated nutrient concentrations and possible eutrophication impacts (including on mussel populations) (Langstone et al., 2003). More recently there appear to have been improvements and signs of eutrophication were not detected in 2014 and 2019 (Exe Estuary Management Partnership, 2014; Environment Agency, 2021b). Furthermore, dissolved oxygen levels in the Exe Estuary are consistent with 'Good' status under the WFD and relevant shellfish and bathing water standards (**Appendix 18**) (Environment Agency, 2021b).

Figure 13: Source apportionment for nitrogen in the Exe Estuary catchment



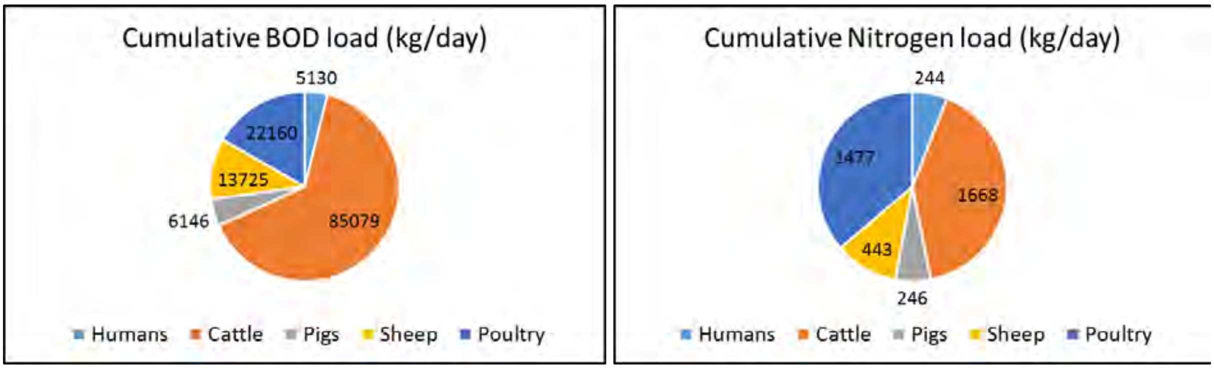
Simple calculations based on livestock numbers and human population numbers in the Exe Estuary catchment indicate that Biochemical Oxygen Demand (BOD) caused primarily by the breakdown of organic carbon and the nitrification of ammonia in human and livestock excreta is likely to be dominated by cattle (dairy and beef herds) (**Table 13; Figure 14**). In terms of relative BOD loading, a dairy cow is equivalent to about 50 people. Therefore, a single herd of 250 dairy cows is equivalent to a population of 12,500, about the size of Honiton (East Devon Catchment Partnership, 2018). A total of 125,045 cattle and 302,595 sheep were recorded within the Exe Estuary catchment according to the 2010 agricultural census. The equivalent human population census in the Exe Estuary catchment was 377,000 (2011) (CEFAS, 2013). Biological oxygen demand specifically due to nitrogen (through nitrification) are dominated by both cattle and poultry faeces (**Table 13; Figure 14**).

Table 13: Calculated daily organic pollution loads (biological oxygen demand) and loads due to nitrogen from human and livestock faeces produced in the Exe Estuary catchment

Data sources: a) Lorimor et al. (2004); b) AgCensus (2010); c) CEFAS (2013); d) Modern Farmer (2021)
Biological oxygen demand, the amount of oxygen required to degrade organic material, i.e. faeces.
Nitrification demands twice as much oxygen as carbon respiration on a molar basis:
Nitrification: a) $2NH_4^+ + \underline{3O_2} \rightarrow 2NO_2^- + 4H^+ + 2H_2O$*; b)* $2NO_2^- + \underline{O2} \rightarrow 2NO_3$ *.....versus*
Respiration: $C + \underline{O_2} \rightarrow CO_2$
The following ratio [2C/N] can be used to calculate the proportion of total BOD, which is due to N

Source	a) Per capita BOD from faeces (kg/day)	b), c) Population number in Exe Estuary Catchment	Cumulative BOD load (kg/day)	d) C/N ratio	Cumulative Nitrogen load (kg/day)
Humans	0.01	377000	5130	20	244
Cattle	0.68	125045	85079	50	1668
Pigs	0.14	45166.7	6146	24	246
Sheep	0.05	302595	13725	30	443
Poultry	0.01	1628488.4	22160	14	1477

Figure 14: Calculated daily organic pollution loads (biological oxygen demand) and loads due to nitrogen from human and livestock faeces produced in the Exe Estuary catchment



8.2 Solutions addressing nutrient pollution

Phosphorus (phosphate)

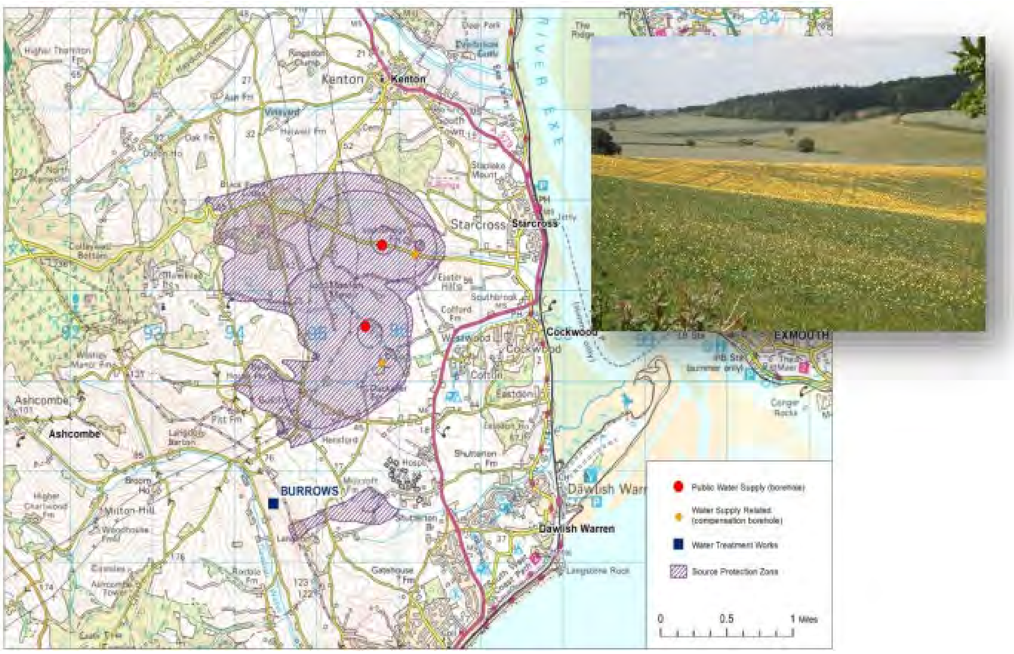
In 2020 South West Water invested substantially in phosphate removal by activated bed Sewage Treatment Works (STWs) (£4.255 million) and filter bed STWs (£4.144 million) (SWW, 2020). No data were available concerning the performance of these asset upgrades at the time of preparing this report.

Nitrogen (nitrate)

Under the Nitrate Pollution Prevention Regulations 2015 farmers operating in Nitrate Vulnerable Zones are required to follow existing rules for: i) using and storing organic manure (manure) or manufactured fertiliser (fertiliser) – e.g. avoiding areas near surface water, boreholes, springs or wells; ii) crop planting and harvesting; iii) managing livestock on farmland/ pasture; iv) managing soils – e.g. calculating the amount of nitrogen available for crop uptake, restricting the timing of ploughing or planting, sowing cover crops, to reduce soil erosion and leaching (DEFRA, 2018a).

Work is being undertaken to reduce the leaching of nitrate fertilisers around the Otter and Cofton Cross (Starcross) drinking water boreholes on the eastern and western sides of the Exe Estuary (**Figure 15**). Through the Environment Agency's 'Diffuse Pollution Pilot Project' and South West Water's Upstream Thinking programme, farms around Cofton and the Otter Valley have implemented cover cropping, integration of fertiliser and manure nutrient supply, and avoidance of slurry and manure spreading at high risk times. Porous light sandy soils in the Otter Valley are particularly susceptible to leaching and nitrate levels are high in the groundwater aquifer (Environment Agency, 2021b). To combat the problem Westcountry Rivers Trust have been trialling a soil conditioning product (ZEBATM), a biodegradable starch polymer which can absorb and retain water over 400 times its original volume.

Figure 15: Water source protection zone for Cofton Cross drinking water boreholes



9 Suspended solids

9.1 Sources

Suspended solids concentrations in the river Exe are due to the erosion of soils and the resuspension of sediments, which increase following heavy rainfall.

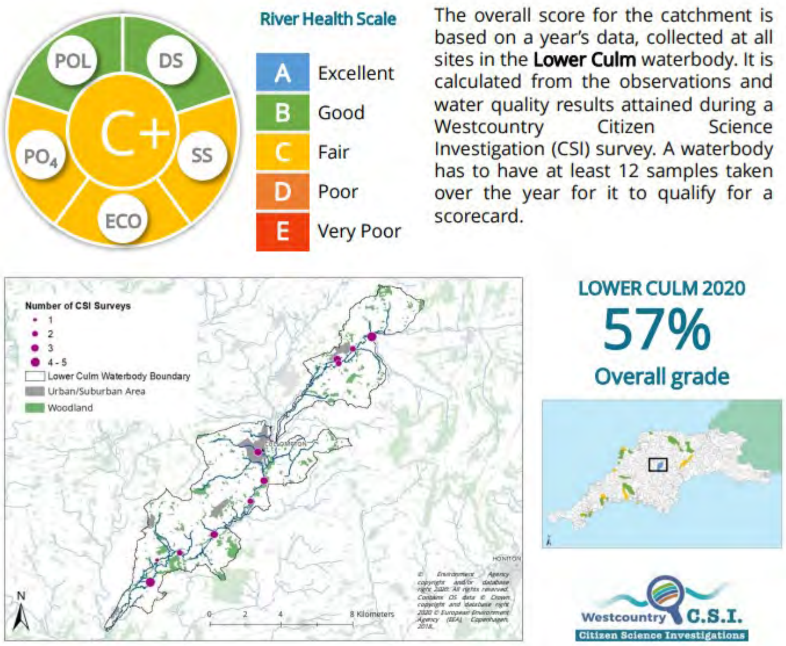
In the Exe main operational catchment suspended solids concentrations have been shown to range considerably from 2-590 mg/L, with mean concentrations of 15.5 and 12.25 mg/L being recorded in 2012 and 2013, respectively (Magdalena et al., 2015). These mean annual concentrations are compliant with a guideline standard of 25 mg/L (annual mean) under the Freshwater Fish Directive (78/659/EEC), prior to the Water Framework Directive, which contains no standards for suspended solids.

Under the East Devon Rural Diffuse Pollution Project Cranfield University showed that: >93% of the land used for maize cultivation in the Culm operational catchment was at high risk of run-off; and 60% was at risk of erosion. Furthermore, a large proportion of farms (19%) in the catchment were identified by the Environment Agency as causing Category 2 (serious) water incidents, with suspended solids concentrations exceeding 500 mg/L (Brown, 2018).

The Lower Culm has been shown to be impacted by elevated concentrations of suspended solids (SS) according to monthly river water sampling and analysis coordinated by Westcountry Rivers Trust's Citizen Science Investigations in 2020 **(Figure 16**).

Figure 16: CSI Score Card for the Lower Culm in 2020

The overall score (C+) is underpinned by sub scores for: Suspended Solids (SS); Phosphate (PO4); Ecosystem health (ECO); Dissolved solids – conductivity (DS); Visible pollution (POL).



9.2 Solutions

Measures to mitigate soil erosion and suspended solids concentrations in the Culm have included establishing crops early in the autumn months, and during dry conditions; planting headland rows and beds across the base of any sloping land; establishing grass (buffer) strips in valleys, or along contours or slopes, or gateways (Brown, 2018).

The Headwaters of the Exe project implemented in Upstream Thinking Phase 2 (2015-2020) has focused on mitigating sediment inputs to the upper Exe catchment (as well as reducing pesticide pollution). As of May 2019, almost 30% of the upper catchment (3,500 ha above the moorland line) has been engaged in Upstream Thinking with physical activities, including establishment of new hedges, farm track management and other works to provide alternative livestock drinking supplies and protect watercourses (Centre for Resilience in Environment Water and Waste, 2021).

10 Metal pollution

10.1 Sources

10.1.1 Pollution from abandoned mines

Post-medieval (post AD1500) iron workings, known as ‘Roman Lode’ are in evidence west of Simonsbath, such as Wheal Eliza, a former iron and copper mine next to the river Barle. Many other mines were established on Exmoor later in the 19th century across Exmoor to Porlock following the success of the Brendon Hill iron mines. These mines spanned Devon and Somerset and exploited thin lodes of high quality ore (often lying below the water table) to produce significant amounts of copper prior to 1900 (Claughton, 1997; Suirat, 2010). It is worth noting that shafts and spoil heaps litter the moors and are not always marked on maps although most are recorded on the Somerset Heritage Environment Register.

Widespread mine closures at the turn of the 19^{th}/ 20^{th} Century and subsequent flooding and leaching of mine waters into ground waters, rivers and streams, has become a major issue in the UK (Gamble et al., 2020). Metal mines in the ore fields of South West England have been highlighted as particularly problematic, continuing to cause pollution, despite being closed for over a hundred years (Environment Agency 2008a). Pollution from abandoned mines affects 5% of water bodies in the South West river Basin District, with surface waters and groundwater being contaminated with dissolved metals such as iron, lead, copper, zinc or cadmium (Environment Agency 2016b). Tin and the metalloid element arsenic are also recognised contaminants in rivers in Devon and Cornwall (Environment Agency, 2008b). Nevertheless the Exe Estuary catchment is not categorised as highly polluted (Coal Board, 2020) and pollution from abandoned mines is not among the reasons for not achieving good status (RNAG) under the Water Framework Directive (Environment Agency, 2021b).

10.1.2 Sewer discharges and sewage sludge biosolids application to land

Aqueous sewage discharges and storm water discharges containing metals derived from domestic sources and urban road runoff (with metal-containing brake dust and engine oils etc.), and also sewage sludge applied to land can also contribute to metal loads entering the Exe estuary catchment.

10.2 Solutions

Although no-one can be held liable for the pollution from abandoned metal mines, which closed long before legal obligations came in to force in 1999 (Environment Agency, 2008a), some pollution mitigation is being implemented in the SW River Basin District (particularly in Cornwall) via the Environment Agency's Abandoned Metal Mines Programme (Environment Agency, 2016b). Pollution control measures include managing runoff from mine spoil heaps, reducing mine flooding and treating mine drainage water (Environment Agency 2008a).

Controlling urban runoff and sewer overflows is also important for reducing metal pollution. Metals are most likely to settle and accumulate in sewage sludge and DEFRA Guidance on the use of biosolids derived from sewage sludge in agriculture should be followed (DEFRA, 2018c) including regularly testing sludge for concentrations of potentially toxic elements (PTEs): arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, zinc). There are restricted times of application of biosolids to crops, maximum permissible annual rates of application to soil and a maximum permissible concentrations in soil (**Appendix 19**). South West Water has reported 98.7-100% compliance with sewage sludge (biosolids) standards in recent annual reporting periods (2014-2020) (SWW, 2020).

11 Emerging contaminants

11.1 Human pharmaceuticals

11.1.1 Sources

The main source of human pharmaceuticals in UK rivers is excretion into sewer systems and the subsequent discharge of effluent from receiving Sewage Treatment Works (STWs) (Melvin et al., 2016). Pharmaceuticals may also enter watercourses following the application of sewage sludge-derived biosolids to land as fertilizer. Available literature suggests that this risk is medium-low for most pharmaceuticals, with the exception of fluoroquinolone antibiotics (e.g. ciprofloxacin), hormones (e.g. ethinylestradiol) and antimicrobials (e.g. triclocarban, triclosan), which are resistant to conventional sewage treatment (Mejías et al., 2021). These (and other) human pharmaceuticals present an emerging environmental concern due to their increasing use, environmental exposure and also their propensity for eliciting unintended effects in wildlife, such as causing antimicrobial resistance and chronic impacts on biodiversity e.g. via hormone disrupting effects on organism development and reproduction (Tyler and Goodhead, 2010; Ford AT, Le Blanc, 2020). The Water Framework Directive watch list of emerging chemicals of concern contains eight substances/groups, five of which are pharmaceuticals, including: i) macrolide antibiotics (erythromycin, clarithromycin, azithromycin); ii) amoxicillin; iii) ciprofloxacin; and hormones iv) ethinylestradiol; v) estradiol and estrone (EU, 2018).

11.1.2 Solutions

UK Water Industry Research (UKWIR), water companies including South West Water and UK regulatory agencies initiated the Chemical Investigations Programme (CIP) to conduct extensive sewage effluent monitoring to assess the removal efficiencies of different sewage treatment processes and to identify pharmaceuticals that present the highest residual risk to the environment post treatment. Based on available dilution data as many as 890 STW in the UK (~13%) were shown to be at risk of exceeding threshold effect concentrations (T) after mixing of their effluents with receiving river water. Pharmaceuticals most likely to exceed threshold effect concentrations were shown to include the hormones - Ethinylestradiol and Estrone; anti-inflammatory drugs - Ibuprofen and Diclofenac; antibiotics - Azithromycin, Clarithromycin and Ciprofloxacin; the betablocker Propranolol; and the stomach acid treatment Ranitidine (Comber et al., 2018).

Monthly CIP monitoring data for a range of pharmaceuticals (11 in total, including hormones, antibiotics, non-steroidal anti-inflammatory drugs, anti-tension and anti-depressant drugs) in final effluents discharged from Countess Wear STW in Exeter in 2010/11 are presented in **Appendix 20**. The data showed that the hormones - Ethinylestradiol, Estradiol and Estrone and the antibiotics – Erythromycin and Oxytetracycline frequently exceeded their respective threshold effect concentrations (**Figure 17**). Dilution by a factor of ≥10 would be required to ensure no unintended effects in wildlife or build-up of antibiotic resistance; this dilution is only likely to be achieved several hundred meters downstream in the Exe Estuary.

Figure 17: Pharmaceutical concentrations in effluent from Countess Wear Sewage Treatment Works in 2010/11 showing exceedance of threshold effect concentrations

The off-the-chart value for Oxytetracycline in July 2010 was 6 μg/L. Threshold effect concentrations (T) for hormones are "Therapeutic Water Concentrations" (Gunnarsson et al., 2019); Threshold effect concentrations (T) for antibiotics: Erythromycin - Predicted No Effect Concentration (for microalgal growth); Oxytetracycline – Minimum Inhibitory Concentration (for bacterial growth) (AMR Industry Alliance, 2018).

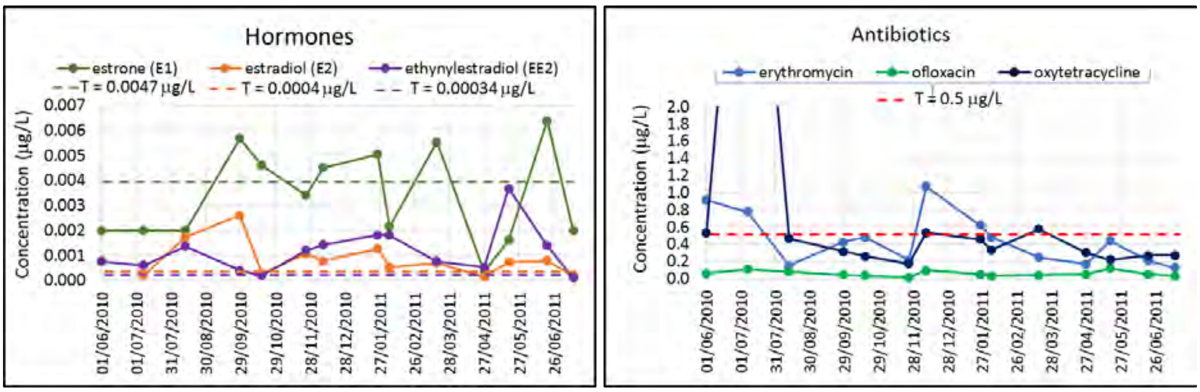


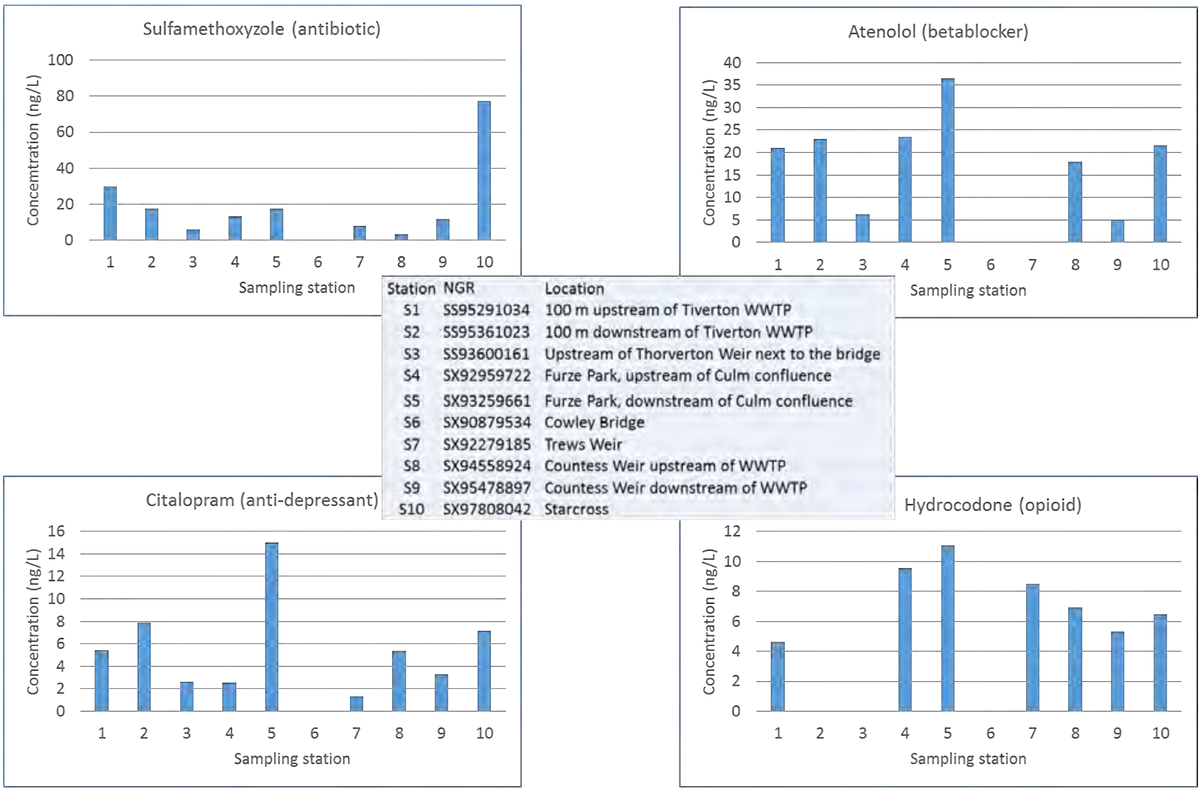
Table 14: Levels of detection of non-steroidal anti-inflammatory drugs (NSAIDs) on Chemcatcher® disks deployed in the River Exe in spring 2013

River water sampling stations	National Grid Coordinates	Mean mass on Chemcatcher® disk (ng)		
		Diclofenac	Ibuprofen	Naproxen
C2) River Exe at Exebridge pumping station	SS93012447	<1	3	4
C5) River Exe upstream of Tiverton sewage treatment works	SS95191104	<1	7	6
C6) River Exe downstream of Tiverton sewage treatment works	SS95381018	2	36	69
C8) River Exe at Northbridge intake	SX93009710	<1	15	30

Spatial variation in concentrations of pharmaceuticals along the river Exe from Dulverton to the intake of Pynes water treatment works in Exeter (**Figure 10**) was demonstrated by Chemcatcher® passive sampling data obtained by Westcountry Rivers Trust in May and June/July 2013 (**Table 14**). The concentrations of three non-steroidal anti-inflammatory drugs (NSAIDS) – Diclofenac, Ibuprofen, Naproxen were generally low (below the analytical limit of detection) in the upper catchment above Tiverton STW (Stations C1-5), and increased by a factor of ~10 at Station C6 (SS95381018) downstream of Tiverton STW. Concentrations remained elevated (3 to 5 times upstream concentrations) at Station C8 - Northbridge intake to the Pynes drinking Water Treatment Plant in Exeter (SX93009710).

Additional spot sampling and analysis of river water was conducted in June 2020 under the South West Environmental and Economic Prosperity (SWEEP) programme (https://sweep.ac.uk/) in collaboration with the Global Monitoring of Pharmaceuticals programme (https://www.globalpharms.org/). Water was sampled from 10 stations (S1 to S10) along the River Exe from above Tiverton STW to Starcross in the Exe Estuary. A total of 58 pharmaceuticals were analysed, of which 19 were detected, albeit at concentrations below threshold environmental effect concentrations (**Appendix 21**). Nevertheless these spatial data identified a number of hotspots. Highest pharmaceutical concentrations in the River Exe generally occurred at the confluence of the River Culm (Station S5 - SX93259661). Concentrations downstream of major Sewage Treatment Works in Tiverton (Station S2 - SS95361023) and Exeter (Station 9 - SX95478897) were not exceptionally high, but concentrations were elevated (particularly for the antibiotic Sulfamethoxazole, but did not exceed minimum selective concentrations - Bengtson Palme Industry Alliance, 2018) in the large water body of the Exe Estuary at Starcross (Station S10 - SX97808042) (**Figure 18**). The elevated concentrations in the estuary may be due to the Kenton and Starcross Sewage Treatment Works (**Appendix 11**) or nearby intermittent discharges e.g. combined sewer overflows.

Figure 18: Pharmaceutical concentrations in the River Exe and Exe Estuary in June 2020.



11.2 Veterinary medicines

11.2.1 Sources

Since the Exe Estuary catchment is dominated by improved grassland used for livestock grazing, there is likely to be a significant farming input of veterinary medicines. Many of these medicines are also used as human pharmaceuticals or pesticides and present similar risks to non-target species, including fish, aquatic invertebrates and plants. A high percentage of topically applied veterinary medicines (e.g. ectoparasite treatments, sheep dips) can be washed off the bodies of livestock. Orally administered medicines can also be excreted by livestock. Consequently, there is a high potential for environmental exposure, including contamination of watercourses by livestock that drink from them or graze nearby (Boxall et al., 2002). Veterinary medicines used to treat domestic pets can also enter watercourses directly or via the domestic sewage network. For example, sewage discharges have been shown to cause widespread contamination of English rivers with two commonly used veterinary flea products fipronil and imidacloprid (Perkins et al., 2021).

Prioritisation of veterinary medicines with the greatest potential for environmental impact has been based collectively on the amount used; usage pattern; metabolism; persistence in manure and slurry; sorption to soil/sediment and persistence in the environment; and ecotoxicity (although data are limited in many cases) (Boxall et al., 2002). Within the highest priority group, antibiotics are ranked highest based on sales volume, followed by coccidiostats (for treating protozoan parasites), organophosphate sheep dip chemicals, anthelmintics (wormers), general anaesthetics, ectoparasiticides, antifungal agents, antiseptics and immunological products (**Appendix 22**). The over-use of antibiotics in human and veterinary medicine has been linked to the development of antibiotic resistance, which poses a severe threat to human and animal health. The Highest Priority Critically Important Antibiotics (HP-CIAs) include: Fluoroquinones, 3rd and 4th generation Cephalosporins and Colistin) (Veterinary Medicines Directorate, 2020). Some other veterinary medicines, such as the insecticide Cypermethrin, are also classified as 'Priority Substances' under the Environmental Quality Standards Directive (2008/105/EC) due to their environmental toxicity and therefore require progressive reduction or phasing out (Environment Agency, 2019d). Substances thought to pose the greatest threat are further identified as 'Priority Hazardous Substances', such as the organophosphate insecticide Diazinon, which was banned in the EU and UK 2006 (**Appendix 22**).

Monitoring data confirming the levels of exposure of veterinary medicines in rivers, including the Exe, are limited. Spot sampling and analysis of water from 10 sampling stations in the River Exe and Exe Estuary was conducted in June 2020 under the South West Environmental and Economic Prosperity (SWEEP) programme (https://sweep.ac.uk/) in collaboration with the Global Monitoring of Pharmaceuticals programme (https://www.globalpharms.org/). Six prioritised veterinary medicines (**Appendix 22**) were included in the chemical analysis - the fluoroquinone antibiotics Enrofloxacin, Lincomyacin, the macrolide antibiotics Tilmicosin and Tylosin, the pyrimidine antibiotic Trimethoprim and the anaesthetic Lidocaine. Only Lidocaine was detected, at 4.4-19.7 ng/L, with peak concentrations recorded at Furze Park, downstream from the confluence of the Culm (SX93259661). Cattle were observed paddling in the river at this location during sampling.

11.2.2 Solutions

The veterinary profession and livestock sectors established targets for responsible reductions in the use of antibiotics in the UK (Responsible Use of Medicines in Agriculture Alliance, 2017). The use of Highest Priority Critically Important Antibiotics (HP-CIAs) in food-producing animals (adjusted for animal population size/biomass) has reduced dramatically from 0.65 mg/kg in 2015 to 0.21 mg/kg (-74%) in 2019 (**Table 15**). The dairy and beef sectors exceeded their target of 50% reduction in cattle injectable HP-CIAs, achieving a 72% reduction between 2016 and 2020 (Veterinary Medicines Directorate, 2020).

Table 15: The use of Highest Priority Critically Important Antibiotics (HP-CIAs) in food-producing animals (adjusted for animal population size/biomass) in 2015 to 2019

	2015	2016	2017	2018	2019	Compared with 2015
Fluoroquinolones (mg/kg)	0.35	0.23	0.16	0.15	0.13	↓ 61%
3rd/4th generation cephalosporins (mg/kg)	0.17	0.14	0.11	0.06	0.03	↓ 82%
Colistin (mg/kg)	0.12	0.02	0.0006	0.0007	0.0002	↓ 99.9%
Total HP-CIAs (mg/kg)	0.64	0.38	0.26	0.21	0.17	↓ 74%

The total amount of antibiotics (all categories, without adjusting for animal population size/biomass) has also reduced over the same period has also reduced dramatically (by -44.5%). The greatest reduction has been achieved for pigs and poultry (-55%), for which the largest volumes of antibiotics are used (**Table 16**).

Table 16: Total amount of active ingredient of antibiotics sold per year in the UK for the treatment of different livestock (tonnes) in 2015 to 2019

Livestock	**2015**	**2016**	**2017**	**2018**	**2019**
Pigs and poultry only	214.2	127.4	97.3	99.7	96.4
Pigs only	49.4	39.7	33.0	23.8	28.5
Poultry only	38.0	26.5	15.0	12.9	14.9
Cattle only	14.1	15.3	13.7	13.0	12.0
Fish only	0.71	1.6	3.4	1.6	3.1
Multiple food-animals (incl. sheep)	29.2	23.4	29.3	27.5	24.4
Companion animals (excl. horse)	12.7	14.7	14.4	13.4	12.5
Horse only	13.4	14.9	6.7	2.4	2.1
combination of food- and non-food-animals	36.5	32.3	35.3	32.1	38.3
Total		**408.2**	**295.8**	**248.1**	**226.4**

Following pollution incidents arising from cypermethrin in sheep dip, the UK government temporarily suspended marketing authorisations of these products in 2006 and these authorisations were withdrawn by manufacturers in 2010 (Environment Agency 2019d). Cypermethrin products are used on cattle and sheep and applied topically as 'pour-on' products. Between 2010 and 2016 the amount of cypermethrin sold for use as a veterinary medicine in the UK was in the range 7000 to 10000kg, rising to over 13,000kg in 2017.

The risks and trends of veterinary medicine use in the Exe Estuary catchment have also been receiving attention in the Headwaters of the Exe project, within the third phase of Upstream Thinking (2020-25). Faecal egg counting is being used to reduce a farm's reliance on wormers by targeting veterinary medicine use to times when it is needed, helping to save cost, reduce chemicals in the environment and to manage wormer resistance. The project is also considering undertaking monitoring of veterinary medicines in the Exe catchment to understand the importance of agriculture livestock and other sources of chemicals, such as domestic sewage and domestic pets (Farming and Wildlife Advisory Group South West, 2021).

12 Summary

The status of the Exe Estuary catchment with respect to key water quality (WQ) elements is summarised below (**Figure 19**).

Figure 19: Status of water quality elements in the Exe Estuary catchment

Priority substances include mercury and poly-brominated diphenylethers (both with atmospheric input pathways). WQ - Water quality. CSOs - Combined Sewer Overlfows. CSF - Catchment Sensitive Farming.

WQ element	Current status	Trend	Confidence in trend	Source id	Measures needed
Faecal indicators			! ! !		CSO spill reduction Flood management
Priority Substances			! ! !		Chemical use stopped
Pesticides			! ! !		Drinking water protection
Metals			! ! !		Continue to monitor sources
Nutrients			! !		Source controls are reducing algal blooms
Suspended solids			! !		CSF measures for maize cultivation
Pharma-ceuticals	?	?	!		Monitoring of sewage discharges
Veterinary medicines	?	?	!		Monitoring of rivers after administration

Key: Red = poor, Amber = moderate, Green = good, = variable, = no change, = improving
! = low confidence, ! ! = medium confidence, ! ! ! = high confidence

All water quality elements can impact on environmental health to some degree; impacts are likely to be greatest for priority hazardous substances, including mercury and poly-brominated diphenyl ethers (PBDEs), which are currently responsible for the failure to achieve 'Good' ecological status under the Water Framework Directive. Pesticides, particularly acid herbicides used to control broad-leaved weeds on arable land and grassland, are also frequently detected in water bodies throughout the non-tidal catchment. Impacts on aquatic plants (macrophytes and algae) are mitigated to some extent by 'first flush' episodes during which short-lived spikes in herbicide concentrations occur in rivers following heavy rainfall events. Faecal pollution, indicated by faecal indicators (*E. coli* and intestinal enterococci) is also associated with heavy rainfall, due to land runoff and sewer overflows. Impacts are mainly due to precautionary restrictions around the use of bathing waters and the sale/consumption of shellfish from estuary and coastal waters – to protect human health. Faecal indicators may not always reliably reflect concentrations of bacterial and viral pathogens that cause human illness, nevertheless the presence of raw sewage in rivers is not socially or environmentally acceptable and is currently one of the biggest environmental issues in the public eye. Metal, nutrient and suspended solids concentrations currently present no major causes for concern, although there are isolated hotspots in the West Exe and Creedy for nutrients and in the Culm for nutrients and suspended solids. Metal pollution from mine water in the upper Exe around Exmoor appears to be minimal. Water quality status is uncertain with respect to human pharmaceuticals and veterinary medicines; more monitoring data are needed to assess the impacts of sewage discharges and inputs from farmyard steadings.

The issue of plastic pollution has not been addressed in this report.

13 Conclusions and recommendations

There are a number of anthropogenic pressures on water quality in the Exe Estuary catchment. The main sources of contamination are diffuse agricultural runoff containing pesticides, nutrients and faecal contaminants and urban waste water (sewage) discharges carrying similar chemical and microbial mixtures. The relative importance of these two major sources varies seasonally and spatially across the catchment depending, for example, on farming activity and rainfall.

Climate change in the form of increasingly frequent high rainfall events during winter months is adding to pressures on water quality by driving increased land runoff and sewer overflows. Although these pressures on water quality extend across much of catchment, there are some notable hotspots in the West Exe and Creedy (e.g. where soils are highly porous with high potential for leaching of nitrate fertilzers) and in the Culm (e.g. where maize cultivation leaves soils exposed and eroded by winter rain).

Activities (agricultural and urban), which impair water quality and flood management upstream in the catchment have the potential to impact negatively activities all the way downstream, including shellfish aquaculture, tourism and conservation (the Exe Estuary hosts one of the largest populations of overwintering water birds in the UK). Contaminant inputs which are closer to these sensitive receptors have greater potential for impact.

The impacts of continuous sewage treatment works (STW) discharges are not notably greater for the larger population centres of Cullompton, Tiverton and Exeter, since treatment processes are scaled in proportion to the populations served.

The impacts of intermittent discharges from storm tank overflows (STOs) and combined sewer overflows (CSOs) are likely to be more significant around the larger population centres. However, data on their operation beyond spill frequency (i.e. spill volumes, time and duration of each spill) are lacking – these data are essential for confirming if overflows correspond with high rainfall and runoff. Progressive reductions in these intermittent discharges of untreated sewage and impacts on water quality will be implemented by water companies, including South West Water under the Environment Act (2021).

Water quality monitoring is key to assuring compliance with environmental policy and legislation, including the updated Environment Act (which calls for progressive reduction in intermittent sewage discharges) and the 25 Year Environment Plan to deliver clean and plentiful water (e.g. through Environmental Land Management Schemes and the new Farming Rules for Water). There are major benefits in collating monitoring data and predictive models from disparate sources (regulatory, research and community initiatives) to build a bigger, more coherent picture, as we have attempted to do in this report. Additional benefits in terms of monitoring efficiency and data comparability would be gained by aligning water and associated environmental sampling and analysis spatially and temporally.

There is a need to better quantify risks to human and environmental health from faecal-borne pathogens, including those with antibiotic (antimicrobial) resistance. There is also an urgent need to quantify concentrations of antibiotics in the environment and to establish the importance of human pharmaceuticals in sewage and sewage sludge versus veterinary medicines, which are also present in sewage, but also used widely in the treatment of livestock within the catchment.

There is a need to better integrate water quality and flood management, since water quality and flood risks are intrinsically linked. This has been highlighted in the most recent South West River Basin Management Planning review https://www.gov.uk/government/collections/draft-river-basin-management-plans-2021#south-west-rbd.

Increasingly frequent storm conditions and sea level rise have the potential to impact directly on the Exe Estuary and coastal zone by scouring sediments and shellfish beds. Major storms in 2013/14 removed a large proportion (>99.9%) of wild mussels in the Exe Estuary and prompted the installation of coastal defences at Dawlish Warren, which have subsequently been eroded by long-shore drift, carrying sediment towards the mouth of the estuary. The increasing sediment loads in the estuary have halted the relaying and farming of mussels leading to both economic and environmental impacts, including reducing habitat and food availability for estuarine bird and fish populations.

Estuarine and coastal shellfish are sensitive receptors, indicators (sentinels) and regulators (bio-remediators) of water quality, as well as highly sustainable food sources. If the shellfish production industry is to flourish, there is an urgent need to give it the same kind of support and financial incentives being offered to terrestrial-based food production from agriculture.

Maintaining and improving water quality in the Exe Estuary catchment will bring numerous ecosystem benefits beyond food production and tourism. These services and benefits need to be properly evaluated, so that remedial measures can be targeted most effectively.

14 Acknowledgements

This work was funded by the Natural Environment Research Council’s Regional Impact from Science of the Environment (RISE) initiative, Grant NE/P011217/1: South West Partnership for Environmental and Economic Prosperity (SWEEP). The authors are very grateful to advice, data and information provided by Amy Binner (University of Exeter Business School), Simon Browning (Westcountry Rivers Trust), Rob Lamboll (Natural England), Anna Gocher (South West Water) and David Smith (South West Water).

15 References

Alleway HK, Gillies CL, Bishop MJ, Gentry RR, Theuerkauf SJ, Jones R (2018). The ecosystem services of marine aquaculture: Valuing benefits to people and nature. BioScience 69: 59–68.

AMR Industry Alliance (2018). Antibiotic Discharge Targets - List of Predicted No-Effect Concentrations https://www.amrindustryalliance.org/wp-content/uploads/2018/09/AMR_Industry_Alliance_List-of-Predicted-No-Effect-Concentrations-PNECs.pdf

Andrews, J. W., Brand, A. R., and Maar, M. (2011). Assessments Isefjord and East Jutland Danish blue shell mussel - MSC Fisheries. https://fisheries.msc.org/en/fisheries/isefjord-and-east-jutland-danish-blue-shellmussel/@@assessments (Accessed 22 March 2021).

APHA Animal and Plant Health Agency (2020). Livestock Demographic Data Group: Cattle population report Livestock population density maps for GB, Updated June 2020. URL (accessed June 2022): http://apha.defra.gov.uk/documents/surveillance/diseases/lddg-pop-report-cattle2020.pdf

Aquafish Solutions (2021). Native oysters – Culture, Restoration & Research http://www.aquafishsolutions.com/?page_id=136

Bengtson Palme Industry Alliance (2018). AMR Industry Alliance Antibiotic Discharge Targets List of Predicted No-Effect Concentrations (PNECs). URL (accessed June 2022): https://www.amrindustryalliance.org/wp-content/uploads/2018/09/AMR_Industry_Alliance_List-of-Predicted-No-Effect-Concentrations-PNECs.pdf

Black, K., Hughes, D.A., 2017. Future of the Sea: Trends in Aquaculture. Foresight, Government Office for Science. URL (accessed April 2022): https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/635209/Future_of_the_sea_-_trends_in_aquaculture_FINAL_NEW.pdf

Boukerb, A. M., Noël, C., Quenot, E., Cadiou, B., Chevé, J., Quintric, L., Cormier, A., Dantan, L., & Gourmelon, M. (2021). Comparative analysis of fecal microbiomes from wild waterbirds to poultry, cattle, pigs, and wastewater treatment plants for a microbial source tracking approach. Frontiers in microbiology, 12, 697553. https://doi.org/10.3389/fmicb.2021.697553

Boxall ABA, Fogg L, Blackwell PA, Kay P, Pemberton EJ (2002). Review of Veterinary Medicines in the Environment R&D Technical Report P6-012/8/TR. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/290328/sp6-012-8-tr-e-e.pdf

Brown C (2018). East Devon Catchment Partnership East Devon Rural Diffuse Pollution Project. https://catchmentbasedapproach.org/wp-content/uploads/2018/12/East-Devon-Diffuse-Pollution-Project-Final-Report.pdf

Campos, C.J.A., Kershaw, S.R., Lee, R.J. (2013). Environmental Influences on Faecal Indicator Organisms in Coastal Waters and Their Accumulation in Bivalve Shellfish. Estuaries and Coasts. https://doi.org/10.1007/s12237-013-9599-y

Carcinus Ltd. (2020). Sanitary Survey - classification zone Lympstone – 2020. https://www.carcinus.co.uk/wp-content/uploads/2021/03/J0591_20_11_18_Lympstone_Oysters_Classification_Zone_Assessment_F

INAL.pdf

Carcinus Ltd. (2021). Exe Estuary - Sanitary survey review. https://www.carcinus.co.uk/wp-content/uploads/2021/03/J0591_20_07_16_Exe_Estuary_Sanitary_Survey_Review_v4.0_FINAL.pdf

Carmichael, R. H., Walton, W. and Clark, H. (2012). Bivalve-enhanced nitrogen removal from coastal estuaries. Canadian journal of fisheries and aquatic sciences, 69, pp: 1131-1149.

CEFAS, Centre for Environment Fisheries and Aquaculture Science (2013). Sanitary survey of the Exe estuary. Cefas report on behalf of the Food Standards Agency, to demonstrate compliance with the requirements for classification of bivalve mollusc production areas in England and Wales under EC regulation No. 854/2004, Cefas.

CEFAS, Centre for Environment Fisheries and Aquaculture Science (2015). Sanitary survey of Lyme Bay. Cefas report on behalf of the Food Standards Agency, to demonstrate compliance with the requirements for classification of bivalve mollusc production areas in England and Wales under EC regulation No. 854/2004.

UK CEH - Centre for Ecology and Hydrology (2010). CS Technical Report No. 9/07 Soils Report from 2007 Emmett, B.A.1 , Reynolds, B.1 , Chamberlain, P.M.2 , Rowe, E.1 , Spurgeon, D.1 , Brittain, S.A.1 , Frogbrook, Z.3 , Hughes, S.1 , Lawlor, A.J.1 , Poskitt, J.1 , Potter, E.1 , Robinson, D.A.1 , Scott, A.1 , Wood, C.1 , Woods, C.1 Centre for Ecology & Hydrology (Natural Environment Research Council) January 2010. URL (accessed June 2022): https://countrysidesurvey.org.uk/sites/default/files/CS_UK_2007_TR9-revised%20-%20Soils%20Report.pdf

UK CEH - Centre for Ecology and Hydrology (2021). Environmental Information and Data Centre. Source apportionment of nutrient contributions to rivers in England and Wales modelled with SAGIS. URL (accessed July 2022): https://data.gov.uk/dataset/9e97da97-3607-4048-a781-a1e98296dc26/source-apportionment-of-nutrient-contributions-to-rivers-in-england-and-wales-modelled-with-sagis

Centre for Resilience in Environment, Water and Waste (2021). Upstream Thinking in action – The River Exe - Evaluating the impact of farm interventions on water quality at the catchment scale. https://www.exeter.ac.uk/media/universityofexeter/research/microsites/creww/upstreamthinking/12_The_River_Exe.pdf

Claughton P (1997). A List of Mines in North Devon and West Somerset 2nd edition (October 1997). http://people.exeter.ac.uk/pfclaugh/mhinf/nd_list/nd_intro.htm
DEFRA, 2015. United Kingdom multiannual national plan for the development of sustainable aquaculture.

Coal Board (2020). Rivers polluted by abandoned metal mines in England. https://www.gov.uk/government/publications/rivers-polluted-by-abandoned-metal-mines-in-england

Comber S, Gardner M, Georges K, Blackwood D, Gilmour D (2012): Domestic Source of Phosphorus to Sewage Treatment Works, Environmental Technology 34(10): 1349–1358 DOI:10.1080/09593330.2012.74700.

Comber, S.D.; Smith, R.; Daldorph, P.; Gardner, M.J.; Constantino, C.; Ellor, B. (2013) Development of a Chemical Source Apportionment Decision Support Framework for Catchment Management. Environ. Sci. Technol. 47, 9824−9832. doi: 10.1021/es401793e

Comber S, Gardner M, Sörme P, Leverett D, Ellor B (2018). Active pharmaceutical ingredients entering the aquatic environment from wastewater treatment works: A cause for concern? Sci Total Environ. 613-614:538-547. doi: 10.1016/j.scitotenv.2017.09.101.

Crowther, J., Kay, D., Anthony, S., Gooday, R., Burgess C., and Douglass, J. (2016), Developing a methodology for screening and identifying potential sources of bacteria to improve bathing, shellfish and drinking water quality. Phase 1: To design and scope a suitable methodology. CRW2015_01. https://www.crew.ac.uk/sites/www.crew.ac.uk/files/publication/CRW2015_01_Bacterial_Screening_Main_Report.pdf

Crowther J (2018). Prioritising interventions to reduce diffuse microbial (FIO) pollution from agricultural sources to coastal waters. https://www.southwestwater.co.uk/siteassets/document-repository/environment/agricultural-impacts-on-coastal-waters.pdf
DEFRA, 2017. Explanatory Memorandum to the Water Environment (Water Framework Directive) (England And Wales) Regulations 2017 10–12.

DEFRA (2018a). Rules for farmers and land managers to prevent water pollution. https://www.gov.uk/guidance/rules-for-farmers-and-land-managers-to-prevent-water-pollution

DEFRA (2018b). DEFRA (2018). Farming rules for water: Questions and answers. https://www.farmingadviceservice.org.uk/sites/default/files/docs/2020-09/Farming-rules-for-water-QA-FINAL-vsn-1.pdf

DEFRA (2018c). Guidance: Sewage sludge in agriculture: code of practice for England, Wales and Northern Ireland. https://www.gov.uk/government/publications/sewage-sludge-in-agriculture-code-of-practice/sewage-sludge-in-agriculture-code-of-practice-for-england-wales-and-northern-ireland#producers-test-sewage-sludge

DEFRA (2019). Marine Strategy Part One: UK updated assessment and Good Environmental Status October 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/921262/marine-strategy-part1-october19.pdf

DEFRA (2021a). Drinking Water Safeguard Zones (Surface water). https://environment.data.gov.uk/dataset/1e0002f8-a322-4158-8165-3d688d634a3c

DEFRA (2021b). Drinking Water Safeguard Zones (Groundwater). https://environment.data.gov.uk/dataset/6288b7b0-d465-11e4-b13c-f0def148f590

DEFRA (2021c). Fertiliser usage on farms: Results from the Farm Business Survey, England 2019/20. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/997395/fbs-fertiliseruse-statsnotice-29jun21.odt

Devon Biodiversity Records Centre (2005). Lyme Bay sampling programme. In Natural England (2010). Lyme Bay and Torbay SAC Selection Assessment Document Version 2.5, pages 1-26. http://publications.naturalengland.org.uk/file/3263831

Devon and Severn IFCA, 2019. Temporary Closure of the Public Mussel Beds – Exe. Available [online] at: https://www.devonandsevernifca.gov.uk/content/download/3218/24439/version/1/file/Full+Byelaw+-+Teign+Temporary+Closure+May+2019.pdf. Accessed July 2020.

Devon and Severn IFCA, 2020. Devon and Severn IFCA Mariculture Strategy 2020. Available [online] at: https://www.devonandsevernifca.gov.uk/content/download/5696/39146/version/2/file/Agenda+item+7+D%26S+IFCA+Mariculture+Strategy+2020.pdf

Devon and Severn IFCA, 2021. Exe Estuary Mussel Stock Assessment 2020. Available [online] at: file:///C:/Users/arb213/Downloads/Exe+Mussel+Stock+Assessment+2020+V1.pdf

Devon Wildlife Trust (2014). Culm Grassland: An Assessment of Recent Historic Change. URL (accessed July 2022): https://www.devonwildlifetrust.org/sites/default/files/2018-12/Assessment-of-Historic-Change-in-the-Culm-October-2014.pdf

East Devon Catchment Partnership (2016). East Devon Catchment Action Plan 1–18.

East Devon Catchment Partnership (2018). East Devon Catchment Action Plan 1–18. https://catchmentbasedapproach.org/wp-content/uploads/2018/12/C22_action-plan_Jul_2018.pdf
East Devon Catchment Partnership (2021). https://catchmentbasedapproach.org/get-involved/east-devon/

Everaert G, Ruus A, Hjermann DØ, Borgå K,Green N, Boitsov S, Jensen H, Poste A (2017). Additive models reveal sources of metals and organic pollutants in norwegian marine sediments. Environmental Science & Technology 51 (21), 12764-12773. DOI: 10.1021/acs.est.7b02964

Environment Agency (2008a). Abandoned mines and the water environment, Science project SC030136-41. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291482/LIT_8879_df7d5c.pdf

Environment Agency (2008b). Assessment of Metal Mining-Contaminated River Sediments in England and Wales. Science Report: SC030136/SR4. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291646/scho1108bozd-e-e.pdf

Environment Agency (2009). Water for life and livelihoods. River Basin Management Plan South West River Basin District Annex D: Protected area objectives. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/295779/gesw0910bstt-e-e.pdf

Environment Agency (2013). Exe Estuary Flood and Coastal Erosion Risk Management Strategy - Strategic Environmental Assessment (SEA) Environmental Report. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/292814/LIT_8613_3fd4d1.pdf

Environment Agency (2016a). Surface Water Safeguard Zone Action Plan Summary River Exe. https://environment.data.gov.uk/portalstg/sharing/rest/content/items/41e6febcbabd415f996a780f9b907c74/data

Environment Agency (2016b). Water for life and livelihoods - Part 1 : South West river basin district River basin management plan Updated: December 2015. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/718339/South_West_RBD_Part_1_river_basin_management_plan.pdf

Environment Agency, 2018a.Notice EX6 7YG, Mrs B J Salter,Mrs N J Drew-Ryeland, Mr David Ryeland: environmental permit application. https://www.gov.uk/government/publications/ex6-7yg-mrs-b-j-saltermrs-n-j-drew-ryeland-mr-david-ryeland-environmental-permit-application-advertisement/ex6-7yg-mrs-b-j-saltermrs-n-j-drew-ryeland-mr-david-ryeland-environmental-permit-application

Environment Agency, 2018b. Notice EX6 7YF, Lord Haldon Limited: environmental permit application Published 4 May 201. https://www.gov.uk/government/publications/ex6-7yf-lord-haldon-limited-environmental-permit-application-advertisement/ex6-7yf-lord-haldon-limited-environmental-permit-application

Environment Agency (2019a). Polybrominated diphenyl ethers (PBDEs): sources, pathways and environmental data October 2019. https://consult.environment-agency.gov.uk/++preview++/environment-and-business/challenges-and-choices/user_uploads/polybrominated-diphenyl-ethers-pressure-rbmp-2021.pdf

Environment Agency (2019b). Mercury: sources, pathways and environmental data October 2019. https://consult.environment-agency.gov.uk/++preview++/environment-and-business/challenges-and-choices/user_uploads/mercury-pressure-rbmp-2021.pdf

Environment Agency (2019c). Water Quality Archive (WIMS) https://environment.data.gov.uk/water-quality/view/explore

Environment Agency (2019d). Cypermethrin: Sources, pathways and environmental data October 2019. https://consult.environment-agency.gov.uk/++preview++/environment-and-business/challenges-and-choices/user_uploads/cypermethrin-pressure-rbmp-2021.pdf

Environment Agency (2020a). Water Environment (Water Framework Directive) shellfish water protected areas in England.

Environment Agency (2020b). Drinking Water Protected Areas (Surface Water). https://data.gov.uk/dataset/3d136e9a-78cf-4452-824d-39d715ba5b69/drinking-water-protected-areas-surface-water

Environment Agency (2020c). Drinking Water Safeguard Zones (Surface Water). https://data.gov.uk/dataset/6ac22521-2e77-4dc8-ba90-6bb55d2ea3b8/drinking-water-safeguard-zones-surface-water

Environment Agency (2021a). Policy paper: River basin planning process overview. Published 22 October 2021. https://www.gov.uk/government/publications/river-basin-planning-process-overview/river-basin-planning-process-overview

Environment Agency (2021b). Catchment Data Explorer - SW River Basin District https://environment.data.gov.uk/catchment-planning/RiverBasinDistrict/8

Environment Agency (2021c). Drinking Water Safeguard Zones and NVZs Information Summary https://environment.data.gov.uk/farmers/

European Council 2004a Regulation (EC) No 852/2004 of the European Parliament and of the Council of 25 June 2004 on the Hygiene of Foodstuffs.

European Council 2004b Regulation (EC) No 853/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific hygiene rules for food of animal origin.
European Council 2004a Regulation (EC) No 854/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption

European Commission (2006). Commission Regulation (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs.

European Commission (2018). Commission Implementing Decision (EU) 2018/840 of 5 June 2018 establishing a watch list of substances for Union-wide monitoring in the field of water policy pursuant to Directive 2008/105/EC of the European Parliament and of the Council and repealing Commission Implementing Decision (EU) 2015/495.

Exe Estuary Management Partnership (2014b) 1. Background to the Exe Estuary. In: State of the Exe Estuary, 2014.p 1–15.

Exe Estuary Management Partnership (2021). Wildlife designations. https://www.exe-estuary.org/visitor-information/wildlife/wildlife-designations/

FAO, Food and Agriculture Organization (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. (Rome, 2020). http://www.fao.org/3/ca9229en/ca9229en.pdf

Farming and Wildlife Advisory Group South West (2021). Headwaters of the Exe Project.
https://www.fwagsw.org.uk/headwaters-of-the-exe

Food Standards Agency (2009). Managing Farm Manures for Food Safety: Guidelines for growers to reduce the risks of microbiological contamination of ready-to-eat crops.
https://www.food.gov.uk/sites/default/files/media/document/manuresguidance%20%281%29.pdf

Food Standards Agency (2015). Chemical contaminant monitoring. - Chemical contaminant results. https://www.food.gov.uk/business-guidance/chemical-contaminant-monitoring

Food Standards Agency (2022). Shellfish Classifications England and Wales 2021-22: Designated bivalve mollusc production areas in England and Wales 2021/22. URL (accessed April 2022): https://www.food.gov.uk/business-guidance/shellfish-classification

Ford AT, Le Blanc GA (2020). Endocrine Disruption in Invertebrates: A Survey of Research Progress. Environmental Science & Technology 54 (21): 13365-13369 DOI: 10.1021/acs.est.0c04226

Foundation for Water Research (2019). Urban Pollution Management Manual, 3rd edition. Updated 7 January 2019 http://www.fwr.org/UPM3/

Frost TM, Austin GE, Calbrade NA, Mellan HJ, Hearn RD, Stroud DA, Wotton SR, Balmer DE (2018). Waterbirds in the UK 2016/17: The Wetland Bird Survey. BTO, RSPB and JNCC, in association with WWT. British Trust for Ornithology, Thetford.

Frost, T.M., Calbrade, N.A., Birtles, G.A., Hall, C., Robinson, A.E., Wotton, S.R., Balmer, D.E. & Austin, G.E. 2021. Waterbirds in the UK 2019/20: The Wetland Bird Survey. BTO, RSPB and JNCC, in association with WWT. British Trust for Ornithology, Thetford

FSA, Food Standards Agency (2021). Pathogen Surveillance in Agriculture, Food and the Environment (PATH-SAFE). URL: https://www.food.gov.uk/news-alerts/news/ps192-million-for-cross-government-surveillance-project-to-protect-public-health

FSA, 2021. Shellfish classification: Food Standards Agency [WWW Document]. Shellfish Classif. Note. URL https://www.food.gov.uk/business-guidance/shellfish-classification (accessed 7.5.21).

Gamble B, Anderson M, Griffiths JS (2020). Hazards associated with mining and mineral exploitation in Cornwall and Devon, SW England (Chapter 13). Geological Society, London, Engineering Geology Special Publications, 29, 321-367, 9 June 2020, https://doi.org/10.1144/EGSP29.13

Grabowski, J.H., Brumbaugh, R.D., Conrad, R.F., Keeler, A.G., Opaluch, J.J., Peterson, C.H., Piehler, M.F., Powers, S.P. and Smyth, A.R., 2012. Economic valuation of ecosystem services provided by oyster reefs. Bioscience, 62(10), 900-909.

Gunnarsson L, Snape JR, Verbruggen B, Owen SF, Kristiansson E, Margiotta-Casaluci L, Österlund T, Hutchinson K, Leverett D, Marks B, Tyler CR (2019). Pharmacology beyond the patient – The environmental risks of human drugs. Environment International 129: 320-332. https://doi.org/10.1016/j.envint.2019.04.075.

Hassard F, Gwyther CL, Farkas K, Andrews A, Jones V, Cox B, Brett H, Jones DL, McDonald JE, Malham SK (2016). Abundance and distribution of enteric bacteria and viruses in coastal and estuarine sediments - a review. Frontiers in Microbiology 7:1692 https://doi.org/10.3389/fmicb.2016.01692

Hawkes HA (1998). Origin and development of the Biological Monitoring Working Party score system, Water Research 32(3): 964-968. https://doi.org/10.1016/S0043-1354(97)00275-3.

Highlands and Islands Enterprise, 2017. The Value of Aquaculture to Scotland - A Report for Highlands and Islands Enterprise and Marine Scotland.

HM Government (2015). The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015. SI:2015/1623. https://www.legislation.gov.uk/uksi/2015/1623/pdfs/uksiod_20151623_en_auto.pdf

HM Government (2016). The Shellfish Water Protected Areas (England and Wales) Directions 2016. SI: 2016/138 https://www.legislation.gov.uk/uksi/2016/138/pdfs/uksiod_20160138_en.pdf

HM Government (2018a). South Inshore and South Offshore Marine Plan July 2018. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/726867/South_Marine_Plan_2018.pdf

HM Government (2018b). A Green Future: Our 25 Year Plan to Improve the Environment. URL (accessed January 2022): https://www.gov.uk/government/publications/25-year-environment-plan

HM Government (2018c). The Future Farming and Environment Evidence Compendium. URL (accessed January 2022): https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/683972/future-farming-environment-evidence.pdf

HM Government (2021a). 2021 Bathing Water Profiles https://environment.data.gov.uk/bwq/profiles/
HM Government (2021b). Review of the water industry national environment programme (WINEP). https://www.gov.uk/government/consultations/review-of-the-water-industry-national-environment-programme-winep

House of Commons Environmental Audit Committee (2022). Water quality in rivers: Fourth Report of Session 2021–22. https://committees.parliament.uk/publications/8460/documents/85659/default/

Huntington, T., & R. Cappell (2020). English Aquaculture Strategy. Final Report. Produced by Poseidon Aquatic Resources Management Ltd for the Seafish Industry Authority. 80 pp + appendices https://www.seafish.org/document/?id=9efe670c-847b-4a4f-b8ec-72f2e5396df6

Johnston D., Parker K. & Pritchard J. 2007. Management of abandoned minewater pollution in the United Kingdom. *In*: Cidu R. & Frau F. (eds) *Water in Mining Environments*. Proceedings of the IMWA Symposium, Cagliari, Mako Edizioni, 209–213.
JNCC (2008). Ramsar Information Sheet: UK11025 Exe Estuary. JNCC: Version 3.0, 13/06/2008, Pages 1-10. https://jncc.gov.uk/jncc-assets/RIS/UK11025.pdf

JNCC. 2011. UKBAP-PriorityHabitatDescriptions-Rev-2011.pdf. JNCC. https://data.jncc.gov.uk/data/2728792c-c8c6-4b8c-9ccd-a908cb0f1432/UKBAPPriorityHabitatDescriptions-Rev-2011.pdf (Accessed 22 March 2021).

Kay, D., Anthony, S., Crowther, J., Chambers, B.J., Nicholson, F.A., Chadwick, D., Stapleton, C.M., Wyer, M.D., 2010. Microbial water pollution: A screening tool for initial catchment-scale assessment and source apportionment. Sci. Total Environ. 408, 5649–5656. https://doi.org/10.1016/j.scitotenv.2009.07.033

Keeler SP Huff JE (2009). Identification of Staphylococcus spp. and aerobic gram-negative bacteria from the cloacae of migratory shorebirds (Family Scolora Cidae) from Delaware Bay, New Jersey Journal of the Pennsylvania Academy of Science 83(1): 34-37.

Kendon M (2015). Editorial: the UK storms of winter 2013/2014. *Weather* 70, 39–40. doi: 10.1002/wea.2474

Kendon M, McCarthy M, Jevrejeva S, Matthews A, Sparks T, Garforth J (2021). State of the UK Climate 2020. International Journal of Climatology 41(S2): 1-76.

Kershaw, S., Acornley, R., 2009. Classification of bivalve mollusc production areas in England and Wales: Sanitary Survey Report, Cefas.

Knot M (2021). Birds on the Exe tide line Apr 9, 2021. https://tidelines.uk/blog/birds-on-the-exe-tide-line/Brown A. R., Webber J., Zonneveld S., Carless D., Jackson B., Artioli Y., Miller P. I., Holmyard J., Baker-Austin C., Kershaw S., Bateman I. J. & Tyler C. R. 2020b 'Stakeholder perspectives on the importance of water quality and other constraints for sustainable mariculture', Environmental Science and Policy, 114. doi: 10.1016/j.envsci.2020.09.018.

Land PE, Torres R, Jackson BW, Miller PI, Brown AR (2022). Identifying possible sources of faecal pollution in coastal shellfish waters using particle back trajectory modelling. Environmental Monitoring and Assessment (submitted).

Langstone WJ, Chesman BS, Burt GR, Hawkins SJ, Readman J, Worsfold P (2003). Site Characterisation of the South West European Marine Sites - Exe Estuary SPA. MBA Report, http://plymsea.ac.uk/id/eprint/65/1/occ_pub_10.pdf

La Peyre, M.K., Humphries, A.T., Casas, A.M., LaPeyre, J.F., 2014. Temporal variation in development of ecosystem services from oyster reef restoration. Ecological Engineering, 63, 34–44.

Lee, R.J., Younger, A.D., 2002. Developing microbiological risk assessment for shellfish purification, in: International Biodeterioration and Biodegradation. Elsevier, pp. 177–183. https://doi.org/10.1016/S0964-8305(02)00084-7

Lee, H., and Lautenbach, S., 2016. A quantitative review of relationships between ecosystem services. Ecological Indicators, 66, 340–351.

Lorimor J, Powers W, Sutton A (2004). Manure Characteristics Manure Management Systems Series MWPS-18 Section 1 SECOND EDI TION. https://www.canr.msu.edu/uploads/files/ManureCharacteristicsMWPS-18_1.pdf

Luisetti, T., Jackson, E.L. and Turner, R.K. (2013). Valuing the European "coastal blue carbon" storage benefit. Marine Pollution Bulletin, 71, pp: 101–106.

Marine Management Organisation (2013). Seascape Assessment for the South Marine Plan Areas. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/321927/1037a.pdf

Maes, J., Teller, A., Erhard, M., Condé, S., Vallecillo, S., Barredo, J.I. et al. (2020). Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment. EUR 30161 EN. Publications Office of the European Union, Ispra, 2020, doi:10.2760/757183, JRC120383.

Magdalena K. Grove, Gary S. Bilotta, Robert R. Woockman, John S. Schwartz (2015). Suspended sediment regimes in contrasting reference-condition freshwater ecosystems: Implications for water quality guidelines and management. Science of The Total Environment 502: 481-492. https://doi.org/10.1016/j.scitotenv.2014.09.054.

Marine Management Organisation (2016). Evidence Supporting the Use of Environmental Remediation to Improve Water Quality in the south marine plan areas. A report produced for the Marine Management Organisation, pp 158. MMO Project No: 1105. ISBN: 978-1-909452-44-2. https://www.gov.uk/government/publications/evidence-supporting-the-use-of-environmental-remediation-to-improve-water-quality-in-the-south-marine-plan-areas-1105

Marine Management Organisation (2020). Evaluation Report of the: Lyme Bay 2 Dredged Material Disposal Site Characterisation Report (PO050) 28 August 2020. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/916625/20200828_PO050_Evaluation_Report.pdf

Maritime UK (2020). Maritime UK - South West Aquaculture Network (SWAN). Aquaculture position paper. URL (accessed March 2022): https://maritimeuksw.org/wp-content/uploads/2020/04/MUK-SW-Aquaculture-Position-FINAL.pdf

McLeod, D.A. and McLeod, C., 2019. Review of the contribution of cultivated bivalve shellfish to ecosystem services. A review of the scientific literature commissioned by Crown Estate Scotland. https://www.crownestatescotland.com/what-wedo/marine/asset/aquaculture

McGrorty, S., Clarke, R., Reading, C., and Goss-Custard, J. 1990. Population dynamics of the mussel Mytilus edulis: density changes and regulation of the population in the Exe estuary, Devon. Marine Ecology Progress Series, 67: 157–169.

Mejías C, Julia Martín J, Santos JL, Aparicio I, Alonso E (2021). Occurrence of pharmaceuticals and their metabolites in sewage sludge and soil: A review on their distribution and environmental risk assessment. Trends in Environmental Analytical Chemistry 30 e00125, https://doi.org/10.1016/j.teac.2021.e00125.

Melvin SD, Leusch FDL (2016). Removal of trace organic contaminants from domestic wastewater: A 639 meta-analysis comparison of sewage treatment technologies. Environ International 92: 183-188.

Modern Farmer (2021). Manure Guide https://modernfarmer.com/2015/05/get-a-load-of-our-manure-guide/

Munro C (2012). Lyme Bay Closed Area Monitoring: what we have learned so far? https://www.marine-bio-images.com/blog/lyme-bay-marine-ecology/lyme-bay-closed-area-monitoring-what-we-have-learned-so-far/

Nag R, Markey BK, Whyte P, O'Flaherty V, Bolton D, Fenton O, Richards KG, Cummins E (2021). A Bayesian inference approach to quantify average pathogen loads in farmyard manure and slurry using open-source Irish datasets. Science of the Total Environment 786, 147474. https://doi.org/10.1016/j.scitotenv.2021.147474.

Natural England (2019). Catchment Sensitive Farming Evaluation Report – Water Quality Phases 1 to 4 (2006-2018) (NE731). URL (accessed December 2021): http://publications.naturalengland.org.uk/publication/4538826523672576

Natural England (2020a). East of Start Point MPA – Marine Conservation Zone. https://jncc.gov.uk/our-work/east-of-start-point-mpa/

Natural England (2020b). European Site Conservation Objectives for Exe Estuary SPA - UK9010081. http://publications.naturalengland.org.uk/publication/6369979498758144 (Accessed 10 March 2021)

Nicholson FA, Bhogal A, Chadwick D, Gill E, Gooday RD, et al. (2013). An enhanced software tool to support better use of manure nutrients: MANNER-NPK. Soil Use and Management 29: 473–484 https://repository.rothamsted.ac.uk/download/f9c273a2e3edb061fd7817644903b792af0b24753dee62fbe2e839dc7923ba4e/1355094/Nicholson_et_al-2013-Soil_Use_and_Management.pdf

OECD Organisation for Economic Cooperation and Development (2021). Fisheries and Aquaculture in United Kingdom January 2021. URL (accessed June 2022): https://www.oecd.org/agriculture/topics/fisheries-and-aquaculture/documents/report_cn_fish_gbr.pdf

OSPAR (2021). Updated audit trail of OSPAR Environmental Assessment Criteria (EAC) and other assessment criteria used to distinguish above and below threshold. Hazardous Substances and Eutrophication Series. https://www.ospar.org/documents?v=46271

Pateman D, White C, Lincoln G (2018). Countess Wear Stormwater UV Irradiation Plant - shellfish harvesting activity in the River Exe set for growth due to improved water quality brought about by targeted sewerage asset improvements. UK Water Projects 2018-2019 - Virtual Edition. https://waterprojectsonline.com/wp-content/uploads/case_studies/2018/South_West_Water_Countess_Wear_2018.pdf

Perkins R, Whitehead M, Civil W, Goulson D (2021). Potential role of veterinary flea products in widespread pesticide contamination of English rivers. Science of The Total Environment 755(1): 143560. https://doi.org/10.1016/j.scitotenv.2020.143560.

Pinn E (2021). Ecosystem services goods and benefits derived from UK commercially important shellfish. Seafish Report June 2021. file:///C:/Users/arb213/Downloads/Ecosystem%20Services,%20Goods%20and%20Benefits%20Derived%20From%20UK%20Commercially%20Important%20Shellfish%20(1).pdf

Posford Duvivier (1998a) Exmouth Approach Channel Study, Report to Lyme Bay and South Devon Coastal Group, 32 pp.

Posford Duvivier (1998b) Lyme Bay and South Devon Shoreline Management Plan, 2 Volumes. Report to Lyme Bay and South Devon Coastal Group.

Posford Duvivier (1999) SCOPAC Research Project: Sediment Inputs to the Coastal System, Summary Document, Report to SCOPAC, 54 pp and 11 Appendices.

Rivers Trusts (2021). State of our Rivers Report https://www.theriverstrust.org/key-issues/state-of-our-rivers#main-content.

Rullens, V., Lohrer, A.M., Townsend, M. and Pilditch, C.A., 2019. Ecological mechanisms underpinning ecosystem service bundles in marine environments – a case study for shellfish. Frontiers in Marine Science, doi: 10.3389/fmars.2019.00409

Scherer NM, Gibbons HL, Stoops KB, Muller M (1995) Phosphorus Loading of an Urban Lake by Bird Droppings, Lake and Reservoir Management, 11:4, 317-327, DOI: 10.1080/07438149509354213

SCOPAC (2013). Holcombe to Straight Point (including Exe estuary). https://www.scopac.org.uk/scopac_sedimentdb/exe/exe.htm

Seed, R., and Suchanek, T. 1992. Population and community ecology of *Mytilus*. In the mussel *Mytilus*: Ecology, Physiology, Genetics and Culture pp. 87–169.

Sheehan EV, Stevens TF, Gall SC, Cousens SL, Attrill MJ (2013) Recovery of a temperate reef assemblage in a marine protected area following the exclusion of towed demersal fishing. PLoS ONE 8(12): e83883. https://doi.org/10.1371/journal.pone.0083883

Sheehan EV, Bridger D, Cabre LM, Cartwright A, Cox D, Rees D, Holmes LA, Pittman SJ (2019). Bivalves boost biodiversity. Journal of the Institute of Food Science and Technology 33(2): 18-21.

Sheehan EV, Holmes LA, Davies BFR, Cartwright A, Rees A, Attrill MJ (2021). Rewilding of protected areas enhances resilience of marine ecosystems to extreme climatic events. Frontiers in Marine Science 8:1182. https://doi.org/10.3389/fmars.2021.671427.

Shumway SE, Davis C, Downey R, Karney R, Kraeuter J, Parsons J, Rheault R, Wikfors G (2003). Shellfish aquaculture — In praise of sustainable economies and environments. World Aquaculture 34(4): 15-17.

Smaal, A., Ferreira, J.G., Grant, J., Petersen, J.K. and Strand, Ø. (2019). Goods and services of marine bivalves, Springer, Cham, pp 315-316.

Suirat M (2010). Mining on Exmoor. Somerset CC, Heritage Environment Register. https://www.victoriacountyhistory.ac.uk/explore/sites/explore/files/explore_assets/2010/03/22/MINING_ON_EXMOOR.doc

SWW (2018). Environment Plan to 2050. https://www.southwestwater.co.uk/siteassets/document-repository/our-vision-2020-2050/2050-environment-plan.pdf

SWW (2019). South West Water and Bournemouth Water Final Water Resources Management Plan August 2019 https://www.southwestwater.co.uk/siteassets/document-repository/environment/sww-bw-wrmp19---finalplan_aug2019.pdf

SWW (2020). Annual Performance Report and Regulatory Reporting. https://www.southwestwater.co.uk/siteassets/document-repository/annual-reports/sww-aprr-2020-online-v2-003.pdf

SWW (2021a). Storm overflows: Event and duration monitoring 2020. https://www.southwestwater.co.uk/SysSiteAssets/document-repository/business-plan-2020-2025/south-west-water-2020-storm-overflows.pdf

SWW (2021b). Upstream Thinking 2015-2020: An overview of progress contributing to 10 years of Upstream Thinking in the South West. https://www.southwestwater.co.uk/siteassets/document-repository/environment/j121-sww-ust-v7-290920.pdf

SWW (2021c). Downstream Thinking & Sustainable Drainage Pilot projects 2015-20: WaterShed Exmouth. https://www.southwestwater.co.uk/environment/working-in-the-environment/sustainable-drainage/pilot-projects/watershed-exmouth/

SWW (2022). Bioresources & Water Resources Markets https://www.southwestwater.co.uk/commercial-services/bioresources/

Townsend I, Jones L, Broom M, Gravell A, Schumacher M, Fones GR, Greenwood R, Mills GA (2018). Calibration and application of the Chemcatcher® passive sampler for monitoring acidic herbicides in the River Exe, UK catchment. Environmental Science and Pollution Research 25:25130–25142 https://doi.org/10.1007/s11356-018-2556-3

Theuerkauf, S. J., Eggleston, D. B., & Puckett, B. J. (2019). Integrating ecosystem services considerations within a GIS-based habitat suitability index for oyster restoration. PLoS ONE, 14, e0210936. https://doi.org/10.1371/journal.pone.0210936

Theuerkauf, SJ, Barrett, LT, Alleway, HK, Costa-Pierce, BA, St. Gelais, A, Jones, RC. (2021) Habitat value of bivalve shellfish and seaweed aquaculture for fish and invertebrates: Pathways, synthesis and next steps. Reviews in Aquaculture.; 00: 1– 19. https://doi.org/10.1111/raq.12584

Thomas, O., 2019. Exe Estuary Mussel Stock Assessment 2019. Report for Devon and Severn Inshore Fisheries and Conservation Authority. Available [online] at: https://www.devonandsevernifca.gov.uk/content/download/5652/38809/version/1/file/Exe+Mussel+Stock+Assessment+2019.pdf. Accessed July 2020.

Tyler CR, Goodhead RM (2010). Impacts of hormone-disrupting chemicals on wildlife. In Silent Summer: The State of Wildlife in Britain and Ireland. Ed Maclean N. Published by Cambridge University Press, pp. 125 - 140. https://doi.org/10.1017/CBO9780511778230.011

UK Government, 2017. Dawlish Warren beach management scheme. Policy paper. Available [online] at: https://www.gov.uk/government/publications/dawlish-warren-beach-managementscheme/dawlish-warren-beach-management-scheme. Accessed July 2020.

UK Centre for Ecology and Hydrology (2021). National River Flow Archive. Available [online] at: https://nrfa.ceh.ac.uk/data/search

Uncles RJ, Stephens JA, Smith RE (2002). The dependence of estuarine turbidity on tidal intrusion length, tidal range and residence time. Continental Shelf Research 22: 1835-1856.

van der Schatte Olivier A, Jones L, Le Vay L, Christie M, Wilson J, Malham SK (2018). A global review of the ecosystem services provided by bivalve aquaculture. Reviews in Aquaculture 1–23, doi: 10.1111/raq.12301.

Veolia (2011). Countess Wear United Kingdom - Wastewater treatment. https://cms.esi.info/Media/documents/134247_1313501116864.pdf

Webber JL, Charles R Tyler, Donna Carless Ben Jackson, Diana Tingley, Phoebe Stewart-Sinclair, Yuri Artioli, Ricardo Torres, Giovanni Galli, Peter I. Miller, Peter Land, Sara Zonneveld, Melanie C. Austen, A Ross Brown (2021). Impacts of land use on water quality and the viability of bivalve shellfish mariculture in the UK: a case study and review for SW England. Environmental Science and Policy 126: 122-131.

Veterinary Medicines Directorate (2020). UK Veterinary Antibiotic Resistance and Sales Surveillance Report UK-VARSS 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/950126/UK-VARSS_2019_Report__2020-TPaccessible.pdf

West Country Rivers Trust (2014). East Devon Catchment Partnership Environmental Services Evidence Review 24 Sept 2014. https://issuu.com/westcountryriverstrust/docs/east_devon_evidence_review_1-1

WFD UKTAG (2008). River Assessment Methods Benthic Invertebrate Fauna River Invertebrate Classification Tool (RICT) By Water Framework Directive - United Kingdom Advisory Group (WFDUKTAG). https://www.wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20water%20environment/Biological%20Method%20Statements/river%20invertebrates.pdf

Williams, C., Davies, W. and Kuyer, J., 2018. A valuation of the Chichester HarbourvProvisioning Ecosystem Services provided by shellfish. Report for Sussex Inshore Fisheries and Conservation Authority (SxIFCA). https://nefconsulting.com/wpcontent/uploads/2018/03/Chichester-Shellfish-Valuation-Report-2018.pdf

Zhao Q, Liu Y (2019). Is anaerobic digestion a reliable barrier for deactivation of pathogens in biosludge? The Science of the Total Environment 668, 893–902. https://doi.org/10.1016/j.scitotenv.2019.03.063

Appendices to the Report:

Assessment of Water Quality status, drivers and impacts in the Exe Estuary Catchment and implications for ecosystem health and services including Shellfish Aquaculture

WESTCOUNTRY RIVERS TRUST

Contents

NOTE: Section numbering refers to that in the accompanying report:

Assessment of Water Quality status, drivers and impacts in the Exe Estuary Catchment and implications for ecosystem health and services including Shellfish Aquaculture

1 Legal framework for the protection of water quality in the UK

1.1: Water Framework Directive

The Water Framework Directive (WFD) interlinks or subsumes several ‘daughter’ Directives and Regulations. These include the Drinking Water Directive (98/83/EC), Groundwater Directive (2006/118/EC), Urban Waste Water Treatment Directive (91/271/EEC), Sewage Sludge (use in agriculture) Directive (86/278/EEC), Bathing Water Directive (2006/7/EC), Ecological Quality Standards Directive (2008/105/EC), Freshwater Fish Directive (78/659/EEC) and the Shellfish Waters Directive (79/923/EEC).

The objective of the WFD is to achieve by 2027 at least ‘Good’ ecological status for all surface waters, freshwater rivers and lakes, transitional waters (estuaries), coastal waters up to 1 nautical mile offshore, or ‘High’ ecological status for internationally important protected conservation areas such as the Exe Estuary (**Section 3.2**). Assessment of ecological status is based on a number of biological quality elements supported by physical and chemical quality elements (outlined in more detail in **Section 4**). Under the WFD, chemical status is assessed up to 12 nautical miles offshore (overlapping with the Marine Strategy Framework Directive (see **below**).

Measures for improving water quality are designed and implemented via regional River Basin Management Plans (RBMPs). The South West RBMP covers the South West River Basin District, which extends from Lands End to the Isle of Wight and to Weston-super-Mare (Environment Agency, 2020). RBMPs focus in particular on water bodies that need special protection from potentially harmful activities (e.g. municipal, agricultural and industrial activities) due to their specific designated uses, including nature conservation, drinking water abstraction, bathing, fisheries and shellfish production (see **below**).

1.2: Marine Strategy Framework Directive

The Marine Strategy Framework Directive (MSFD - 2008/56/EC) assesses and protects the environmental status of marine waters from the high water spring tide mark up to the outer limit of the UK’s Exclusive Economic Zone (EEZ). The Directive requires that Good Environmental Status (GES) is achieved in marine waters by 2020 and sets out eleven qualitative descriptors which describe what the environment will look like when GES has been achieved (**Appendix 1**). Descriptor 5 requires nutrient pollution and excess algal growth (eutrophication) to be minimised, while Descriptors 8 and 9 refer to ensuring that concentrations of contaminants cause no adverse effects in marine organisms or in humans who consume seafood.

The MSFD is enacted in the UK by the Marine and Coastal Access Act (2009) and in Lyme Bay by the South Marine Plan. This Marine Plan has the prime objective (1) “To encourage effective use of space to support existing, and future sustainable economic activity through co-existence, mitigation of conflicts and minimisation of development footprints.” Objective (11) is “To complement and contribute to the achievement or maintenance of Good Ecological Status or Potential under the Water Framework Directive and Good Environmental Status under the Marine Strategy Framework Directive.” (HM Government, 2018a).

1.3: Shellfish water protected areas

There are 96 designated shellfish water protected areas in England and 32 (on third) of these are located within the South West River Basin District (Environment Agency, 2020), including five in the Exe estuary and three in adjoining coastal waters in Lyme Bay (West) (**Section 4.4**). Shellfish Water Protected Areas (England and Wales) Directions 2016 require that 75% of shellfish samples taken within any 12 month period from all UK shellfish waters should contain ≤ 300 *E. coli* /100 mL in shellfish flesh and intravalvular fluid (HM Government, 2016). However, the classification of shellfish waters is ultimately determined by EU food hygiene regulation (EC) No. 854/2004 (European Council, 2004a) requiring Official Control monitoring of *E. coli* in shellfish against a series of classification limits (A, B and C – **Appendix 1 Table 1**). Classifications determine whether or not shellfish are safe to eat, or if they require purging (depuration) before consumption (and EU export) (**Section 4.4**).

Appendix 1 Table 1: Classification of shellfish waters based on faecal indicator organism (FIO) counts in bivalve shellfish (minimum of 10 samples required per year for Class A; 8 samples for Class B & C)

Class	*E. coli* mean probable number /100g shellfish flesh	Treatment required
A	≤ 230 (80% of sample results) < 700 (100% of sample results)	May go direct for human consumption
B	≤ 4600 (90% of sample results) < 46000 (100% of sample results)	Must be depurated, heat treated or relaid to meet Class A
C	≤ 46000 (100% of sample results)	Must be laid for at least 2 months, followed where necessary by treatment in a Purification Centre to meet Class A requirements
P	> 46000	Prohibited from production or collection

Food Hygiene Regulation (EC) No 1881/2006 also sets maximum permitted levels of chemical contaminants in bivalve shellfish to safeguard human consumers (**Section 4.3**).

1.4: Freshwater fish protected areas

There are 954 Freshwater Fish Waters in the SW River Basin District (Environment Agency, 2009). The objective for freshwater fish waters designated under the Freshwater Fish Directive (78/659/EEC), prior to the Water Framework Directive, is to protect or improve the quality of running or standing freshwaters to enable them to support indigenous fish species or species which are desirable for water management purposes. Water quality standards for freshwater fish (including sensitive salmonid fish and less sensitive cyprinid fish) are laid out in the Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015 (HM Government, 2015). Standards representing 'Good' water quality for salmonid fish include: dissolved oxygen (≥75%); Biochemical Oxygen Demand (≤4 mg/L); acid neutralising capacity (≥75); total ammonia as nitrogen (0.2 mg/L).

1.5: Bathing water protected areas

Bathing water protected areas are those in which a large number of people (~100 people) are expected to bathe at any one time. There are 194 designated coastal bathing waters (and zero freshwater bathing waters) in the SW River Basin District. There are 29 bathing water areas in Lyme Bay West (between Dartmouth and Beer); 18 are located between Hopes Nose (Torquay) and Beer and 2 of these are located at the mouth of the Exe Estuary (**Section 4.5**). Under the UK Bathing

Water Regulations 2013 (SI:1675, enacting the EU Bathing Water Directive 2006/7/EC), waters must be tested for faecal indicator organisms (FIOs – *E. coli* and/or intestinal enterococci) at weekly intervals between 1 May and 30 September, with a minimum of 20 samples tested annually. There are three measurement criteria for each FIO, including a minimum standard, which must be met in order for a bathing area to pass and standards of Good and Excellent water quality (**Appendix 1 Table 2**). In addition to these criteria, bathing water quality is assessed based on: blue-green algal (cyanobacterial) concentrations; proliferations of macro-algae (seaweed) or marine phytoplankton; the presence of waste or any other incident that may pose a risk to bathing water quality and bathers' health.

Appendix 1 Table 2: Standards for coastal and transitional waters

(A)Based upon a 95-percentile evaluation; (B)Based upon a 90-percentile evaluation.

Faecal Indicator Organism	Classifications based on number of colony forming units per 100 mL of water		
	"Excellent"	"Good"	"Sufficient"
Intestinal enterococci	100(A)	200(A)	185(B)
Escherichia coli	250(A)	500(A)	500(B)

1.6: Drinking water protected areas

Drinking Water Protected Areas (Surface Water) are areas in which raw water is abstracted for drinking water supplies from rivers and reservoirs. Water quality monitoring and environmental standards are set out in the Water Supply (Water Quality) Regulations 2016 (SI:2016/614, enacting the EU Drinking Water Directive). There are 120 Drinking Water Protected Areas (DrWPAs) in the SW River Basin District, including three in the Exe Estuary catchment, which cover a total area of 113.6 km^2 (17.3% of the Exe Estuary catchment – 655 km^2) (**Section 4.6**). Drinking water protected areas: Exe (Barle to Culm - GB108045015050) 103.2 km^2; Exe (Haddeo to Barle - GB108045015060) 3.7 km^2 ha; Exe (Culm to Creedy - GB108045009060) 6.9 km^2; plus Budleigh Book, Dawlish Water, West Lyn River and the Bray. Drinking water from these areas is abstracted from the River Exe and treated at two water treatment works; Allers WTW located upstream of Tiverton and Pynes WTW located upstream of Exeter (SWW, 2019). Potential drinking water pollutants requiring monitoring, management/treatment are listed in **Appendix 1 Table 3** and include a wide range of agents including faecal bacteria (*E. coli* and Enterococci), nitrate, heavy metals, pesticides and aromatic hydrocarbons.

An additional area of 402 km^2 (61.4%) of the Exe Estuary catchment is covered by a Surface Water Safeguard Zone (SWSGZ5012) (DEFRA, 2021a). Safeguard zones are non-statutory areas identified for safeguarding 'at risk' abstractions where land use management practices and other activities can affect the quality of the untreated water. There are also a number of Ground Water Safeguard Zones in the catchment (Environment Agency, 2021c).

1.7: Nutrient sensitive areas (Nitrate Vulnerable Zones)

Nitrate Vulnerable Zones (NVZs) are defined within the Nitrates Directive (91 / 676 /EEC) and Nitrate Pollution Prevention Regulations 2015 (SI: 2015/668) as areas of land that drain into nitrate polluted waters and contributes to the pollution of those waters. Such waters i) Contain or could contain, if preventative action is not taken, nitrate concentrations > 50 mg/l; ii) are eutrophic, or become eutrophic, if preventative action is not taken. NVZs are designated by the Secretary of State under the Nitrate Regulations (England) and maps indicating the extent of these zones are compiled by the Environment Agency (2021b). There are four Nitrate Vulnerable Zones (NVZs) in the Exe main catchment, which are highlighted as being at risk from agricultural nitrate pollution: Aylesbeare stream NVZ (S535); Clyst NVZ (S536); River Weaver NVZ (S537); Mid Devon NVZ including Yeo/Creedy (S538) (**Section 4.7**).

1.8: Nature conservation protected areas

The Exe Estuary and Lyme Bay contain a number of designated shellfish production sites and European Marine Sites/ Natura 2000 Sites recognised as having international conservation importance under the Conservation of Habitats and Species (Amendment) (EU Exit) Regulations 2019 and international Conventions such as the Ramsar Convention on wetlands. These sites, collectively known as Marine Protected Areas (MPAs), have the objectives of achieving 'Maximum ecological potential (in the case of the Exe Estuary, which is heavily modified) and 'High' ecological potential (in the case of unmodified water bodies, including Lyme Bay). Currently the Exe Estuary and Lyme Bay (West) are classified as having only 'Moderate' ecological potential and 'Moderate' ecological status, respectively (**Sections 4.1 and 4.2**).

Appendix 1 Table 3: Drinking Water Protected Area water quality standards

Table A

Microbiological parameters

Part I: Directive requirements

(1)	*(2)*	*(3)*	*(4)*	*(5)*
Item	*Parameters*	*Concentration or value (maximum)*	*Units of measurement*	*Point of compliance*
1.	*Enterococci*	0	number/100ml	Consumers' taps
2.	*Escherichia coli (E. coli)*	0	number/100ml	Consumers' taps

Part II: National requirements

(1)	*(2)*	*(3)*	*(4)*	*(5)*
Item	*Parameters*	*Concentration or value (maximum)*	*Units of measurement*	*Point of compliance*
1.	Coliform bacteria	0	number/100ml	Service reservoirs(*) and water treatment works
2.	*Escherichia coli (E. coli)*	0	number/100ml	Service reservoirs and water treatment works

(*) Compliance required as to 95% of samples from each service reservoir (regulation 4(6)).

Table B

Chemical parameters

Part I: Directive requirements

(1)	*(2)*	*(3)*	*(4)*	*(5)*
Item	*Parameters*	*Concentration or value (maximum)*	*Units of measurement*	*Point of compliance*
1.	Acrylamide	0.10	µg/1	(i)
2.	Antimony	5.0	µgSb/1	Consumers' taps
3.	Arsenic	10	µgAs/1	Consumers' taps
4.	Benzene	1.0	µg/1	Consumers' taps
5.	Benzo(a)pyrene	0.010	µg/1	Consumers' taps
6.	Boron	1.0	mgB/1	Consumers' taps
7.	Bromate	10	µgBrO3/1	Consumers' taps
8.	Cadmium	5.0	µgCd/1	Consumers' taps
9.	Chromium	50	µgCr/1	Consumers' taps
10.	Copper	2.0	mgCu/1	Consumers' taps

11.	Cyanide	50	µgCN/1	Consumers' taps
12.	1, 2 dichloroethane	3.0	µg/1	Consumers' taps
13.	Epichlorohydrin	0.10	µg/1	(i)
14.	Fluoride	1.5	mgF/1	Consumers' taps
15.	Lead	10	µgPb/1	Consumers' taps
16.	Mercury	1.0	µgHg/1	Consumers' taps
17.	Nickel	20	µgNi/1	Consumers' taps
18.	Nitrate(ii)	50	mgNO3/1	Consumers' taps
19.	Nitrite(ii)	0.50	mgNO2/1	Consumers' taps
		0.10		Treatment works
20.	Pesticides(iii) (iv)	0.030	µg/1	Consumers' taps
	Aldrin			
	Dieldrin	0.030	µg1	Consumer's taps
	Heptachlor			
	Heptachlor epoxide			
	Other pesticides	0.10	µg/l	Consumers' taps
21.	Pesticides: total(v)	0.50	µg/1	Consumers' taps
22.	Polycyclic aromatic hydrocarbon(vi)	0.10	µg/1	Consumers' taps
23.	Selenium	10	µgSe/1	Consumers' taps
24.	Tetrachloroethene and Trichloroethene(vii)	10	µg/l	Consumers' taps
25.	Trihalomethanes: Total(viii)	100	µg/1	Consumers' taps
26.	Vinyl chloride	0.50	µg/1	(i)

(i) The parametric value refers to the residual monomer concentration in the water as calculated according to specifications of the maximum release from the corresponding polymer in contact with the water. This is controlled by product specification.

(ii) See also regulation 4(2)(d).

(iii) See the definition of "pesticides and related products" in regulation 2.

(iv) The parametric value applies to each individual pesticide.

(v) "Pesticides: total" means the sum of the concentrations of the individual pesticides detected and quantified in the monitoring procedure.

(vi) The specified compounds are—

— benzo(b)fluoranthene;

— benzo(k)fluoranthene;

— benzo(ghi)perylene;

— indeno(1,2,3-cd)pyrene.

The parametric value applies to the sum of the concentrations of the individual compounds detected and quantified in the monitoring process.

(vii) The parametric value applies to the sum of the concentrations of the individual compounds detected and quantified in the monitoring process.

(viii) The specified compounds are—

— chloroform;

— bromoform;

— dibromochloromethane;

— bromodichloromethane

Part II: National requirements

(1) *Item*	*(2)* *Parameters*	*(3)* *Concentration or value (maximum)*	*(4)* *Units of measurement*	*(5)* *Point of compliance*
1.	Aluminium	200	µgA1/1	Consumers' taps
2.	Colour	20	mg/1 Pt/Co	Consumers' taps
3.	Iron	200	µgFe/1	Consumers' taps
4.	Manganese	50	µgMn/1	Consumers' taps
5.	Odour	Acceptable to consumers and no abnormal change		Consumers' taps
6.	Sodium	200	mgNa/1	Consumers' taps
7.	Taste	Acceptable to consumers and no abnormal change		Consumers' taps
8.	Tetrachloromethane	3	µg/1	Consumers' taps
9.	Turbidity	4	NTU	Consumers' taps

SCHEDULE 2

Regulation 2

Indicator parameters

(1) *Item*	*(2)* *Parameters*	*(3)* *Specification concentration or value (maximum unless otherwise stated) or state*	*(4)* *Units of measurement*	*(5)* *Point of compliance*
1.	Ammonium	0.50	mgNH4/1	Consumers' taps
2.	Chloride(i)	250	mgC1/	Supply point(*)
3.	*Clostridium Perfringens (including spores)*	0	Number/100ml	Supply point(*)
4.	Coliform bacteria	0	Number/100ml	Consumers' taps
5.	Colony counts	No abnormal change	Number/1ml at 22°C	Consumers' taps, service reservoirs and treatment works
6.	Conductivity(i)	2500	µS/cm at 20°C	Supply point(*)
7.	Hydrogen ion	9.5 (maximum) 6.5 (minimum)	pH value	Consumers' taps
8.	Indicative dose(ii)	0.10	mSv	Supply point(*)
	(a) gross alpha	0.1	Bq/1	Supply point(*)
	(b) gross beta	1	Bq/1	Supply point(*)
9.	Radon(iii)	100	Bq/1	Supply point

11.	Total organic carbon (TOC)	No abnormal change	mgC/l	Supply point
12.	Tritium (for radioactivity)[(iv)]	100	Bq/l	Supply point[(*)]
13.	Turbidity	1	NTU	Treatment works

[(i)] The water should not be aggressive.

[(ii)] Where treatment to reduce the level of radionuclides in water intended for human consumption has been taken, monitoring must be carried out to ensure the continued efficacy of the treatment.

[(iii)] Remedial action may be taken by the Secretary of State on radiological protection grounds without further consideration and deemed to be justified where radon concentrates exceed 1,000 Bq/1.

[(iv)] If tritium concentration exceeds its parametric value, an investigation (which may include analysis) of the presence of artificial radionuclides is required.

[(*)] May be monitored from samples of water leaving treatment works or other supply point, as no significant change during distribution.

2 Wetland types and areas in the Exe Estuary

Data from JNCC (2008).

Code	Wetland	Area (%)	Area (km2)
F	Estuary water (low tide)	32.5	7.62
G	Intertidal sand/mudflats	32.5	7.62
Tp	Freshwater marsh/pools	10	2.35
E	Sand/shingle shores/dunes	10	2.35
9	Canals and drainage channels	5	1.17
H	Saltmarsh	5	1.17
B	Intertidal seagrass	5	1.17

3 WFD operational catchments and water bodies in the Exe Estuary catchment

Exe Main catchment **West Exe catchment** **Clyst and Culm catchment**

Waterbodies

Exe Main	Creedy and West Exe	Clyst and Culm
Ben Brook	Alphin Brook	Aylesbeare Stream
Brockey River	Colebrook	Bolham River
Burn (Exe)	Culvery River	Ford Stream (EXE)
Calverleigh Stream	Dawlish Water	Fulford Water
Danes Brook	Ford Brook (EXE)	Grindle Brook
Dart (Exe)	Holly Water	Halberton Stream
Exe (Barle to Culm)	Jackmoor Brook	Ken Stream
Exe (Creedy to Estuary)	Kenn	Lower Clyst
Exe (Culm to Creedy)	Lower Creedy	Lower Cranny Brook
Exe (Haddeo to Barle)	Lower Yeo (Creedy)	Lower Culm
Exe (Quarme to Haddeo)	Matford Brook	Madford River
Exe (Source to Quarme)	Middle Creedy	Middle Culm
Iron Mill Stream	Shobrooke Lake	Polly Brook
Lower Barle	Troney	Sheldon Stream
Lower Batherm	Upper Creedy	Spratford Stream
Lower River Haddeo	Upper Yeo (Creedy)	Upper Clyst
Lowman		Upper Cranny Brook
Middle Barle		Upper Culm
North Brook (East Devon)		Weaver
Pinkery Pond		
Pulham		
Quarme		
Sherdon Water		
Upper Barle		
Upper Batherm		
Upper River Haddeo		
Wimbleball Lake		

4 Water courses entering the Exe Estuary and Lyme Bay West

Unconstrained confluences with the Exe Estuary

• Withycombe Brook (Exe (tidal) GB108045008950) – terminating in a heavily engineered open-topped concrete culvert structure located in Exmouth.

• Polly Brook (GB108045008980) - Confluence is at Exton, where the river passes in two channels, one through a bridge structure and one through a culvert.

• Grindle Brook (GB108045008710) – Confluence with the Clyst in Clyst St Mary.

• North Brook (GB108045009050) – Confluence with the Exe at Countess Wear.

Tidally regulated confluences with the Exe Estuary

• River Exe – confluence at Tews Weir.

• Wotton Brook (Exe (tidal) GB108045008960) – Confluence with the Exe Estuary at Lympstone.

• Exe (GB108045009040) – Flows over St James Weir between Countess Wear and Exminster Marshes and Powderham Banks.

• Alphin Brook (GB108045009020) – Enters the Exe Estuary between Exminster Marshes and Powderham Banks via a siphon under the Exeter Ship Canal which takes all flow under nonflood conditions. Under flood flows, an overflow weir spills into a flood storage area associated with Exminster Marshes.

• Exeter Ship Canal (GB70810015) – Connects with the Exe Estuary at Turf locks between Exminster Marshes and Powderham Bank. The canal is part of the Exe Estuary SSSI designation, including habitats within and outwith the embankments.

• Berry Brook and Main Drain drainage system (GB108045008990) - Enters the Exe Estuary at Turf locks between Exminster Marshes and Powderham Banks, via an undershot sluice adjacent to the entrance to the ship canal.

• River Kenn ((Exe (tidal) - rises in the Haldon Hills and enters the estuary through a tidal gate between Starcross and Powderham.

• Staplake Brook (Exe (tidal) GB108045008930) - Enters the Exe Estuary at Starcross via a flapped outfall on a culvert under the coast road and railway.

• Cockwood Marsh (Exe (tidal) GB108045008920) – Enters the Exe Estuary at Starcross.
The river water body is regulated by a tidal flap under Church Lane on the western side of the harbour.

• Shutterton Brook (Exe (tidal) GB108045008900) – Confluence is with the Exe Estuary at Dawlish Warren.

5 WFD classification

5.1: Classification of surface water bodies in the South West River Basin District (14 September 2021)
https://environment.data.gov.uk/catchment-planning/RiverBasinDistrict/8/objectives
Results for WFD tranche 3 (2027) are not yet available, data in grey are predicted data.

WFD tranches	Ecological status/potential of water bodies (WBs)					
	Bad	Poor	Moderate	Good	High	Total WBs
1) WBs by 2015	5	8	62	160	2	237
2) WBs by 2021	0	0	10	44	0	54
3) WBs by 2027	0	1	13	392	0	406
Total WBs	5	9	85	596	2	697

5.2: Classification of ecological status of surface water bodies in operational catchments (associated with the Exe Estuary) in the East Devon Management Catchment (14 September 2021)
https://environment.data.gov.uk/catchment-planning/ManagementCatchment/3033
Note *Exe main operational catchment includes 26 river reaches and Wimbleball Lake.
Several water bodies in the Exe Estuary catchment, are heavily modified (hyro-morphologically) and must fulfil 'Good ecological potential'. The Exe Estuary is also heavily modified, and as a European Marine Site/ Natura 2000 Site of conservation importance, it must achieve 'Maximum ecological potential'

Operational catchment	Ecological status/potential of water bodies (WBs)					
	Bad	Poor	Moderate	Good	High	Total WBs
Clyst & Culm	1	6	12	0	0	19
Creedy & West Exe	1	5	8	2	0	16
Exe main*	0	1	16	10	0	27
Exe Estuary	0	0	1	0	0	1
Lyme Bay (West)	0	0	1	0	0	1

5.3) Classification of chemical quality status of surface water bodies in operational catchments (associated with the Exe Estuary) in the East Devon Management Catchment (14 September 2021)
https://environment.data.gov.uk/catchment-planning/ManagementCatchment/3033

Operational catchment	Chemical status of water bodies (WBs)				
	Fail	Good	Common RNAG	Additional RNAG	Total WBs
Clyst & Culm	19	0	a, b		19
Creedy & West Exe	16	0	a, b		16
Exe main	27	0	a, b	c	27
Exe Estuary	1	0	a, b	c	1
Lyme Bay (West)	1	0	a, b		1

Reasons for not achieving good (RNAG) chemical status include: exceedance of Environmental Quality Standards (EQS_{biota}) for: a) poly-brominated diphenyl ethers (PBDEs) EQS_{biota} = 0.0085 µg/kg; b) mercury and its compounds EQS_{biota} = 20 μg/kg. Chemicals a) and b) have recently been detected up to 2500× the EQS_{biota} for PBDEs and up to 10× the EQS_{biota} in signal crayfish (*Pacifastacus leniusculus*) in freshwaters and/or blue mussels (*Mytilus edulis*) in transitional and coastal waters in the UK (Environment Agency, 2019a; 2019b; 2021a). Sources of these chemicals are largely atmospheric pollution. Additional reasons for not achieving good (RNAG) chemical status, for named water bodies in the Exe Estuary catchment include: c) Benzo(g-h-i)perylene (in Lower Batherm in Exe Main catchment and Exe Estuary). These chemicals a, b and c are priority hazardous substances listed under the WFD (Environment Agency, 2021b).

6 Marine Strategy Framework Directive qualitative descriptors of Good Environmental Status (GES)

Descriptors (water quality related descriptors are underlined)

Descriptor 1. Biodiversity is maintained

Descriptor 2. Non-indigenous species do not adversely alter the ecosystem

Descriptor 3. The population of commercial fish species is healthy

Descriptor 4. Elements of food webs ensure long-term abundance and reproduction

<u>Descriptor 5. Eutrophication is minimised</u>

Descriptor 6. The sea floor integrity ensures functioning of the ecosystem

Descriptor 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem

<u>Descriptor 8. Concentrations of contaminants give no effects</u>

<u>Descriptor 9. Contaminants in seafood are below safe levels</u>

Descriptor 10. Marine litter does not cause harm

Descriptor 11. Introduction of energy (including underwater noise) does not adversely affect the ecosystem

Contaminant concentrations:

Environmental Assessment Criteria are stipulated by the Oslo Paris Commission (OSPAR); Maximum Permitted Levels of specified contaminants in fish and other seafood caught or harvested for human consumption are stipulated by Regulation (EC) No 1881/2006.

- Metals in biota
- Metals in sediment
- Poly Chlorinated Biphenyls (PCBs) in biota
- PCBs in Sediment
- Poly Aromatic Hydrocarbons (PAH) in biota
- PAH in sediment
- Poly Brominated Diphenyl Ethers (PBDEs) in biota
- PBDEs in sediment
- Radionuclides
- Metals from water and air
- contaminants in coastal waters
- specific pollutants

Biological effects

- Imposex in dogwhelks
- Micronucleus test
- EROD activity
- Bile metabolites
- Liver neoplasm
- Fish disease

7 Assessment criteria for PAHs, PCBs and trace metals in mussels and oysters

From OSPAR (2009):

For poly- chlorinated biphenyls (poly- CBs), OSPAR Environmental Assessment Criteria (EACs - intended to provide the green/red transition point) were estimated from sediment EACs and biota sediment accumulation factors (BSAF). Purple shaded cell are where EACs were not recommended for use by ICES (CBs) or are below the Low Concentration (LC). EC - Commission Regulation No 1881/2006 sets maximum concentration for contaminants in foodstuffs to protect public health. EACpassive - calculated on the basis of BSAFs and sediment EACs.

Compound	LC (µg/kg dry weight)	BAC (µg/kg dry weight) (T_0)	EAC (µg/kg dry weight) (T_1)	EC (µg/kg dry weight) (T_1)	EAC[passive] (µg/kg dry weight) (T_1)
PAHs					
Naphthalene		81.2[b]	340		
Phenanthrene	4.0[a]	12.6[b]	1700		
Anthracene		2.7[b]	290		
Fluoranthene	5.5[a]	11.2[b]	110		
Pyrene	4.0[a]	10.1[b]	100		
Benzo[*bj*]fluoranthene	3.0[a]	[b]			
Benzo[*k*]fluoranthene	1.0[a]	[b]	260		
Benzo[*a*]anthracene	1.0[a]	3.6[b]	80		
Chrysene	4.0[a]	21.8[b]			
Benzo[e]pyrene	2.5[a]	[b]			
Benzo[*a*]pyrene	0.5[a]	2.1[b]	600	50 (10 ww[h] X 5)	
Benzo[*ghi*]perylene	1.5[a]	7.2[b]	110		
Indeno[*1,2,3*-cd]pyrene	1.0[a]	5.5[b]			
C1-Phenanthrene/ Anthracene	7.0[a]	[b]			
C2-Phenanthrene/ Anthracene	7.0[a]	[b]			
C3-Phenanthrene/ Anthracene	6.5[a]	[b]			
C1-DBT	1.0[a]	[b]			
C2-DBT	3.5[a]	[b]			
C3-DBT	3.5[a]	[b]			
Total PAH (11 Parent PAH)	28.0[c]	[b]			
Total PAH (11 Parent + alkylated PAH with LCs)	56.5[d]	[b]			

CBs					
Compound	LC (µg/kg dry weight)	BAC (µg/kg dry weight) (T_0)	EAC (µg/kg dry weight)	EC (µg/kg dry weight) (T_1)	EAC[passive] (µg/kg dry weight) (T_1)
CB28	0.25[e]	[b]	13.5		3.2
CB52	0.25[e]	[b]	80		5.4
CB101	0.25[e]	[b]	5.0		6.0
CB118	0.25[e]	[b]	1.0		1.2
CB138	0.25[e]	[b]	100		15.8
CB153	0.25[e]	1.1[b]	1790		80
CB180	0.25[e]	[b]	26.5		24
ΣICES7CBs	1.0[f]	4.6[b]			
Trace metals (µg/kg dry weight) – mussels					
Determinand	LC (µg/kg dry weight)	BAC (µg/kg dry weight) (T_0)	EAC (µg/kg dry weight)	EC (µg/kg dry weight) (T_1)	EAC[passive] (µg/kg dry weight) (T_1)
Hg	50[g]	140[h]	10	2,500 (500 ww[i] x 5)	
Cd	600[g]	1,940[h]	280	5000 (1,000 ww[i] x 5)	
Pb	800[g]	1,520[h]	8,500	7,500 (1,500 ww[i] x 5)	
Trace metals (µg/kg dry weight) – oysters					
Hg	100[j]	[k]		2,500	
Cd	1,800[j]	[k]		5,000	
PB	800[j]	[k]		7,500	

[a]low concentrations (LC) proposed at MCWG 2008 from the 10th percentile of datasets (Scotland, Spain and France)
[b]Background Assessment Concentrations (BACs) used in the 2005/6 MON assessment to be defined/re-defined for updated BCs or LCs
[c]includes 8 of the 9 parent CEMP PAHs, benzo[*bj*]fluoranthene, benzo[*k*]fluoranthene and benzo[*e*]pyrene.
[d]includes 11 parent PAHs and selected alkylated PAHs. LCs were not proposed for anthracene or naphthalene nor for the alkylated naphthalenes due to a high proportion of samples in the datasets for which the values were below the limits of quantification for these PAHs
[e]LC = 2 x QUASIMEME constant error
[f]LC = 8 x QUASIMEME constant error
[g]low concentrations (LC) proposed at ICES MCWG 2008, median of regional medians
[h]BACs used in 2006/7 MON assessment to be redefined for new LCs
[i] ww, wet weight
[j]calculated using conversion factors proposed at ASMO 08 by France[3]
[k]To be calculated

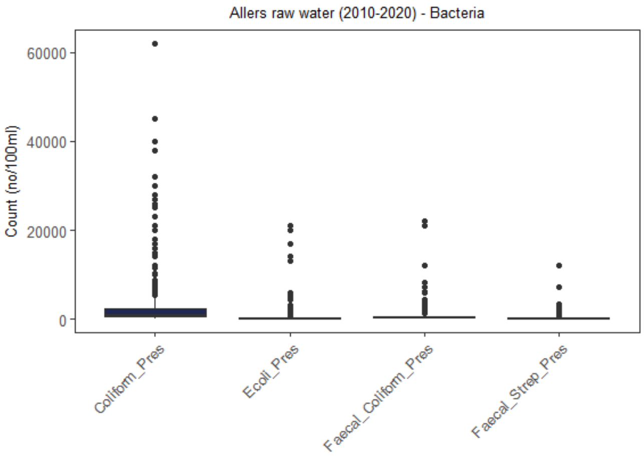
8 Pesticides highlighted to present a risk to the Exe catchment Surface Water Safeguard Zone

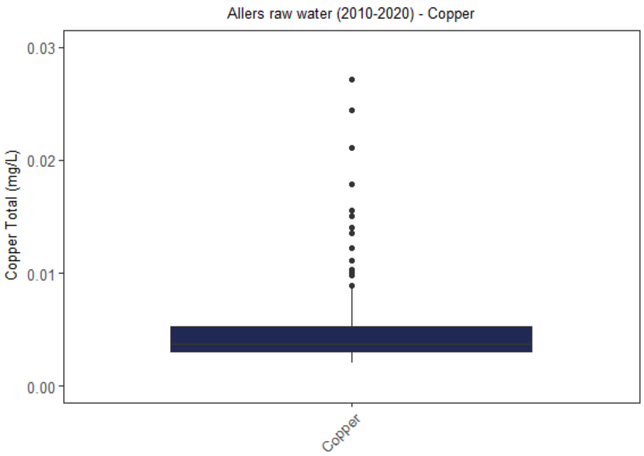
and physical-chemical properties underlying their potential to leach from agricultural land

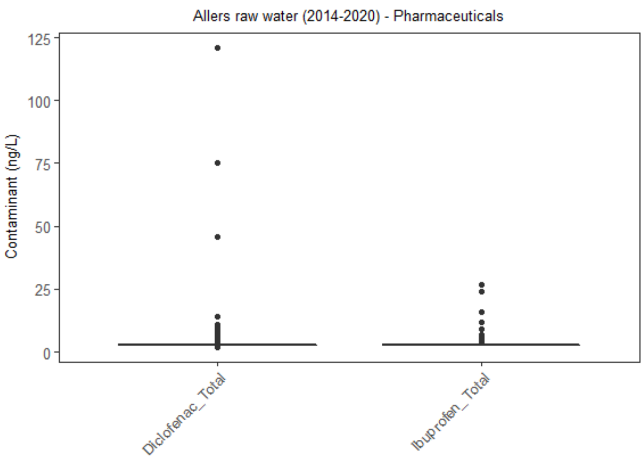
Soil adsorption coefficient (K_f) is the ratio between the amount of pesticide which is adsorbed (bound) to soil particles divided by the amount which is dissolved and mobile in soil pore water.
EC50 is effective concentration causing 50% reduction in growth of freshwater algae (sensitive species)
** EC50 for invertebrates for the slug killer metaldehyde is >78.4* μg/L
The maximum allowable concentration for Mecoprop in saltwater is 1.7 μg/L (Environmental Quality Standard based on saltwater algae).
LC50 is lethal concentration (oral dose) causing 50% mortality in mammals (indication of human toxicity)

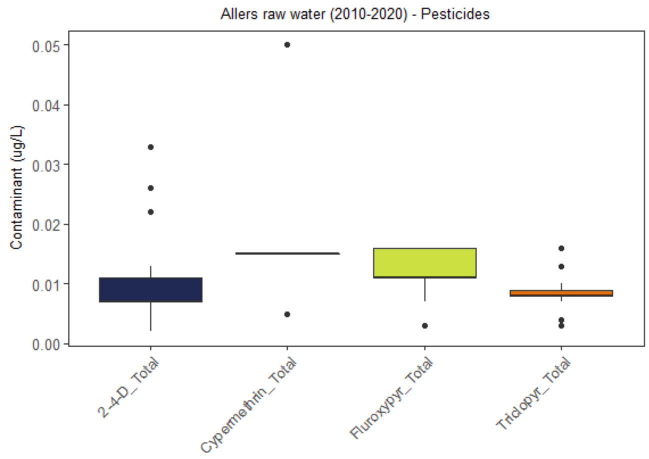
Pesticide	Type	Water solubility @ 20 °C (mg/L)	Soil adsorption coefficient (K_f)	Degradability (half-life in field soil in days)	Toxicity to freshwater algae (EC50 in μg/L)	Toxicity to mammals (LC50 in μg/L)
Chlorotoluron	Herbicide	76	1.3	12.5	82	>10000
MCPA	Herbicide	29390	0.94	25	79.8	962
Mecoprop	Herbicide	250000	1.54	21	16.2	431
Triclopyr	Herbicide	8100	1.02	30	181	630
Metaldehyde	Molluscicide	188	0.69	5.1	75.9*	283

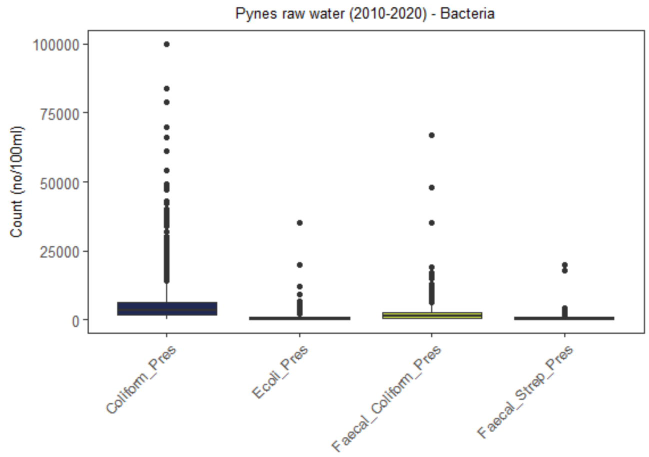
9 South West Water monitoring data indicating the quality of raw water taken in at Allers and Pynes Water Treatment Works (2010-2020)

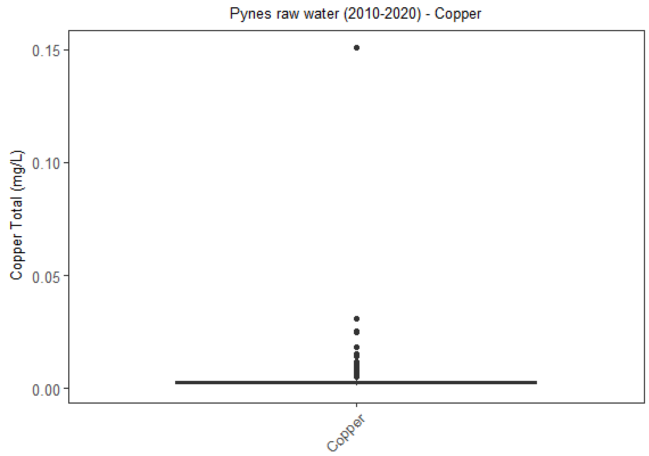


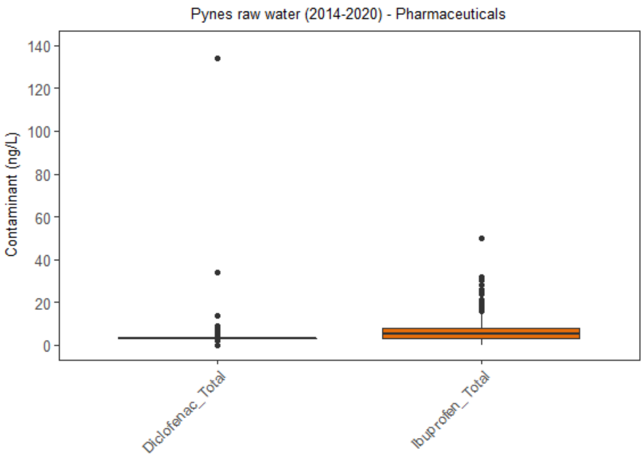




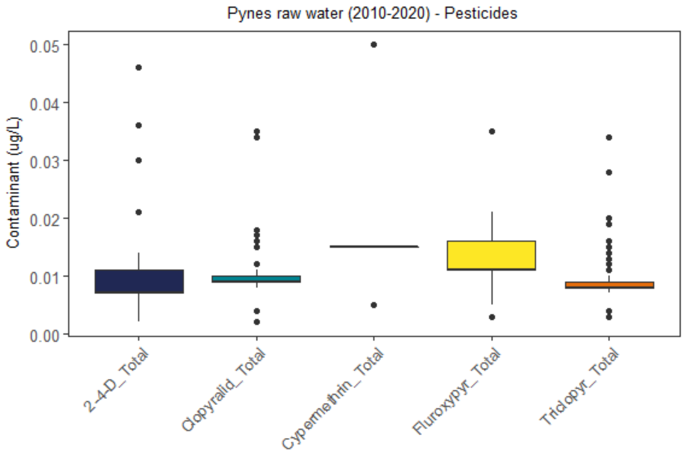

Allers raw water (2010-2020) - Pesticides
Contaminant (ug/L)
0.05
0.04
0.03
0.02
0.01
0.00
2-4-D_Total
Cypermethrin_Total
Fluroxypyr_Total
Triclopyr_Total


Pynes raw water (2010-2020) - Bacteria
Count (no/100ml)
100000
75000
50000
25000
0
Coliform_Pres
Ecoli_Pres
Faecal_Coliform_Pres
Faecal_Strep_Pres


Pynes raw water (2010-2020) - Copper
Copper Total (mg/L)
0.15
0.10
0.05
0.00
Copper



Pynes raw water (2014-2020) - Pharmaceuticals
Contaminant (ng/L)
140
120
100
80
60
40
20
0
Diclofenac_Total
Ibuprofen_Total



Pynes raw water (2010-2020) - Pesticides
Contaminant (ug/L)
0.05
0.04
0.03
0.02
0.01
0.00
2-4-D_Total
Clopyralid_Total
Cypermethrin_Total
Fluroxypyr_Total
Triclopyr_Total

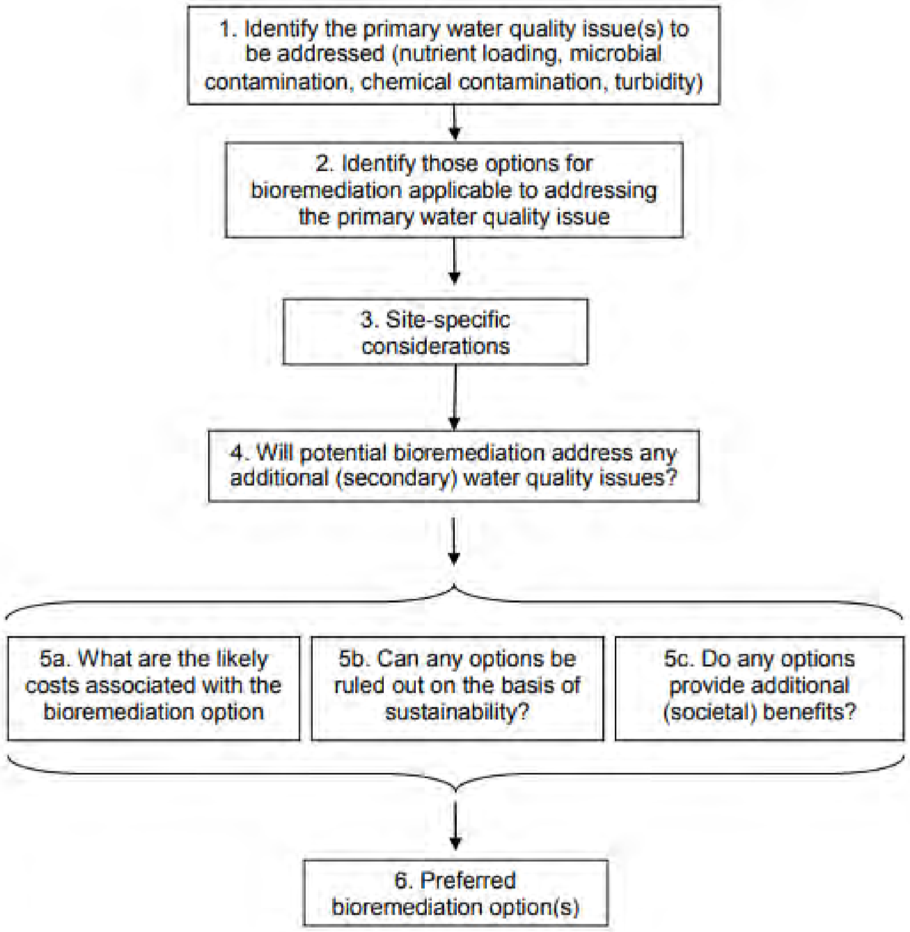
10 The use of bivalve shellfish to bio-remediate water quality in the Exe Estuary

– worked example from MMO Project No: 1105 on Environmental remediation in South Marine Plan Areas (MMO, 2016)

The Exe Estuary has multiple water quality issues:

- The Exe estuary has a well-documented problem with microbial contamination of shellfish.
- The estuary also fails to meet Water Framework Directive standards based on chemical status.
- The catchment area is a Nitrate Vulnerable Zone, and although not a designated eutrophication sensitive area, inorganic nutrient concentrations are too high at present to allow a good status classification under the WFD. A rapidly increasing human population in the catchment could further increase nutrient inputs in the next 20 years.
- High turbidity (as well as nutrient concentrations) is also a potential threat to health of existing intertidal and subtidal seagrass populations. However, it is of note that turbidity may be a limiting factor on the use of the nutrients by the phytoplankton and reducing it may increase the sensitivity of the waters to further eutrophic symptoms.
- Water quality managers have to be aware of potentially conflicting issues, so that solving one problem does not increase another.

The process of selecting the most suitable bioremediation option for a given site follows the steps outlined in the figure below.



Step 1: The Exe requires bioremediation for all of the main water quality issues highlighted (bulleted) above, but the primary issue of concern is judged to be microbial contamination due to the economic value of the shellfish industry at this location. Limiting factors in the Exe estuary for remediation techniques are the lack of available space (< 20 km2) and multiple uses by other sectors such as recreation (Exe Estuary Management Partnership, 2014b). However, paradoxically the remediation of the microbial contamination would increase that recreation use. Identification of microbial contamination input sources followed by hydrodynamic modelling would be necessary to identify the best possible locations for a bioremediation facility to be installed.

Step 2: South marine plan policies give clear guidance that proposals or activities which can deliver an improvement to estuarine water quality (policy S-WQ3b) will be supported by marine planning. Policy S-BIO-7c is more specific and indicates that water filtration, nutrient reduction and chemical sequestration ecosystem service will be supported. Following this direction, the Exe Estuary Management Partnership and all relevant agencies would review the most suitable bioremediation technology. The most effective reduction in microbial loading is via bio-filtration, with rope-grown mussels (*Mytilus edulis*) having the highest efficiency (and therefore requiring least area).

Step 3: Rope-grown mussels would also have the secondary effect of reducing the nutrient load of the Exe Estuary and surrounding waters (noting that locally, in the vicinity of the farm, that metabolically-released ammonia may cause seawater concentrations to be elevated to levels above ambient). It is possible that the chemicals in breach of Environmental Quality Standards may also be removed by bioaccumulation in mussel tissue; this would require further research and modelling of contaminant sources with respect to water flows. Turbidity would probably be reduced in the vicinity of the farm due to phytoplankton consumption and trapping of sediment particles in pseudofaeces. However, rope-grown systems require a water depth of more than 10 m, and this condition severely limits the number of suitable locations in the Exe itself. The next most suitable bioremediation option could be the bottom culture of mussels or oysters (*Ostrea edulis* or *Magallana gigas*, which although less efficient than a rope-grown system, would still have significant biofiltration capacity.

Step 4: The suitability of establishing bottom cultures of bivalves can then be compared with the other drivers: cost, sustainability, societal benefits and conflicts with other marine policies. Draft marine policies have been proposed to regulate the interaction of static objects in the water with recreational boating (S-TR-2c), and to avoid adversely influencing tourism or recreational activities (S-TR-2d). The relative weighting of each driver would become apparent during, for example, stakeholder consultation meetings. Bottom cultivation of all three species is rated as low-to-moderately expensive, with native oyster (*Ostrea edulis*) cultivation scoring high for sustainability, and equal with mussels for additional societal benefits. In this case, the selection of a bioremediation option which, after GIS mapping of constraints in the estuary, could offer a sustainable solution and a wide range of additional benefits to society (e.g. reef-forming habitat, fish nursery function and waste burial).

11 Consented continuous sewage discharges contained within the Exe Estuary catchment, Exe Estuary and Lyme Bay West

Treatment works	NGR	Treatment	Dry weather flow (m3 day-1)
ALLER GROVE STW	SY0529096950	BIOLOGICAL FILTRATION	9
ASHILL STW	ST0860011900	Unspecified	Unspecified
AYLESBEARE STW	SY0358091860	BIOLOGICAL FILTRATION	103
BAMPTON WWTW	SS9541021790	BIOLOGICAL FILTRATION	230
BICKLEIGH STW	SS9385007300	Unspecified	Unspecified
BRAMPFORD SPEKE STW	SX9314097070	BIOLOGICAL FILTRATION	104.54
BRIDGETOWN WWTW	SS9230033230	BIOLOGICAL FILTRATION	Unspecified
BROMPTON REGIS STW	SS9553031200	Unspecified	Unspecified
BRUSHFORD WWTW	SS9267025860	BIOLOGICAL FILTRATION	124
BUCKLAND STW	SX9606071430	BIOLOGICAL FILTRATION	21818
BURLESCOMBE WWTW	ST0653016970	BIOLOGICAL FILTRATION	155
BUTTERLEIGH STW	SS9740007750	Unspecified	Unspecified
CADBURY CROSS STW	SS9065005050	Unspecified	Unspecified
CADELEIGH STW	SS9153008120	Unspecified	Unspecified
CHERITON BISHOP STW	SX7757093550	BIOLOGICAL FILTRATION	144
CHERITON FITZPAINE WWTW	SS8576006130	BIOLOGICAL FILTRATION	115
CLYST HYDON STW	ST0367001620	BIOLOGICAL FILTRATION	7.13
COWLEY BRIDGE STW	SX9064095420	Unspecified	Unspecified
CULLOMPTON WWTW	ST0216006080	BIOLOGICAL FILTRATION	2955
CULMSTOCK STW	ST0992013680	BIOLOGICAL FILTRATION	118
DAWLISH STW	SX9742076470	UV DISINFECTION	4856
DULFORD STW	ST0685005950	Unspecified	Unspecified
DULVERTON SEPTIC TANK	SS9133027640	SEPTIC TANK	Unspecified
DULVERTON WWTW	SS9172027190	BIOLOGICAL FILTRATION	468
DUNKESWELL STW	ST1519008580	BIOLOGICAL FILTRATION/ REED BED	314
EXETER COUNTESS WEIR STW	SX9497089050	UV DISINFECTION	40486
EXFORD STW	SS8567038160	BIOLOGICAL FILTRATION	120
EXMOUTH STW	SY0379079190	UV DISINFECTION	11825
FORETOWN STW	ST0315000010	BIOLOGICAL FILTRATION	4.8
HALBERTON STW	ST0113012320	BIOLOGICAL FILTRATION	208
HELE WHITEWAYS STW	SS9955002050	Unspecified	Unspecified
HELE VILLAGE STW	SS9935002350	Unspecified	Unspecified
HEMYOCK WWTW	ST1339013880	ACTIVATED SLUDGE	446
HOCKWORTHY STW	ST0290020270	BIOLOGICAL FILTRATION	Unspecified
HOLCOMBE ROGUS WWTW	ST0639017980	BIOLOGICAL FILTRATION	119
HUNTSHAM STW	ST0045020350	Unspecified	Unspecified
KENN & KENNFORD STW	SX9276085270	BIOLOGICAL FILTRATION	262
KENTON & STARCROSS	SX9748283180	UV DISINFECTION	1750
KERSWELL STW	ST0782006330	BIOLOGICAL FILTRATION	Unspecified

Treatment works	NGR	Treatment	Dry weather flow (m3 day-1)
KNOWLE STW	SS7831001590	Unspecified	Unspecified
LORDS MEADOW WWTW	SX8572099120	CHEMICAL-PHOSPHATE STRIPPING	4100
MAMHEAD STW	SX9340080350	Unspecified	Unspecified
MARSH GREEN WWTW	SY0419093810	REEDBED	28
MOREBATH STW	SS9535024770	Unspecified	Unspecified
NEWBUILDINGS STW	SS7950003500	Unspecified	Unspecified
NEWTON ST CYRES STW	SX8885098140	ACTIVATED SLUDGE	300
NORTH BOVEY STW	SX7452093750	Unspecified	Unspecified
OAKFORD STW	SS9113021420	Unspecified	Unspecified
OAKLEIGH WWTW	ST1209008480	BIOLOGICAL FILTRATION	Unspecified
OLDWAY END STW	SS8690024950	Unspecified	Unspecified
OTTERTON STW	SY0923084090	UV DISINFECTION	1643
PENNYMOOR STW	SS8646011670	BIOLOGICAL FILTRATION	34
PLYMTREE STW	ST0406003960	BIOLOGICAL FILTRATION	96.8
PORT ROAD WWTW	SX9486079650	BIOLOGICAL FILTRATION	3.6
POUGHILL STW	SS8653008290	PACKAGE TREATMENT PLANT	Unspecified
PUDDINGTON STW	SS8360010730	Unspecified	Unspecified
REWE WWTW	SX9455098840	TREATMENT	429
SAMPFORD PEVERELL WWTW	ST0387013360	WWTW	296
SANDFORD WWTW	SS8339002240	TREATMENT	118
SHILLINGFORD ABBOT STW	SX9135088650	Unspecified	Unspecified
SHILLINGFORD ST GEORGE WWTW	SX9075088050	Unspecified	Unspecified
SHILLINGFORD STW	SS9794023780	Unspecified	Unspecified
SHUTE WWTW	SS8954000080	BIOLOGICAL FILTRATION	12.3
SIDELING CLOSE STW	SX8823087870	PACKAGE TREATMENT PLANT	13.5
SILVERTON WWTW	SS9712001420	ACTIVATED SLUDGE	563.64
SPREYTON STW	SX6987097530	BIOLOGICAL FILTRATION	34
STOODLEIGH STW	SS9250019000	Unspecified	Unspecified
TEDBURN ST MARY STW	SX8248093950	BIOLOGICAL FILTRATION	383
THORVERTON WWTW	SS9359001680	BIOLOGICAL FILTRATION	309
TIVERTON STW	SS9530010300	BIO-FILTRATION & CHEMICAL-PHOSPHATE STRIPPING	6900
UFFCULME WWTW	ST0622011860	BIOLOGICAL FILTRATION	564
UPLOWMAN STW	ST0132015270	BIOLOGICAL FILTRATION	42
WASHFIELD STW	SS9360015300	Unspecified	Unspecified
WHIDDON DOWN STW	SX6929092440	BIOLOGICAL FILTRATION	41
WILLAND WWTW	ST0420010160	TREATMENT	613
WIMBLEBALL RESERVOIR WWTW	SS9640031000	SEPTIC TANK	6.3
WINSFORD STW	SS9110034630	BIOLOGICAL FILTRATION	84
WOODBURY WWTW	SX9979086780	BIOLOGICAL FILTRATION	408
BRADNINCH WWTW	ST0057003310	PRIMARY SETTLEMENT	404
YEOFORD WWTW	SX7894098740	BIOLOGICAL FILTRATION	493
OLD WOODBURY SALTERTON STW	SY0128089340	BIOLOGICAL FILTRATION	201

12 Consented intermittent sewage discharges contained within the Exe Estuary catchment, Exe Estuary and Lyme Bay West

Name	Receiving Environment	NGR	Treatment (if applicable)
121A ST. KATHERINES ROAD CSO	MINCINGLAKE STREAM	SX9419093870	SCREENING
14 CLIFTON ROAD CSO	RIVER EXE VIA SWS	SX9223091880	NONE
15 HAMLIN LANE CSO	NORTH BROOK	SX9417093410	NONE
19 HEAVITREE ROAD CSO	RIVER EXE VIA SWS	SX9223091880	NONE
2 DRYDEN ROAD CSO	NORTH BROOK VIA SWS	SX9430091240	NONE
21 LOWER TOWN CSO	TRIBUTARY OF SPRATFORD STREAM	ST0328014230	NONE
21 WONFORD STREET CSO	NORTHBROOK VIA SWS	SX9429091240	NONE
23 KING EDWARD STREET CSO	RIVER EXE VIA SWS	SX9109093800	NONE
28 CLIFTON ROAD CSO	RIVER EXE VIA SWS	SX9224091880	NONE
34 CLIFTON ROAD CSO	RIVER EXE VIA SWS	SX9224091890	NONE
49 EXETER ROAD CSO	ENGLISH CHANNEL VIA SWS	SX9679077050	SCREENING
50 CASTLE PARK CSO	STREAM (S)	ST1361413585	NONE
ARGYLL ROAD PUMPING STATION	TRIBUTARY OF DURYARD STREAM	SX9212094980	FLOTATION
ASH GROVE CSO	A TRIBUTARY OF THE EXE ESTUARY	SY0003083070	NONE
AYLESBEARE STW	AYLESBEARE BROOK	SY0358091860	SCREENING
BAMPTON STREET CSO	RIVER EXE	SS9535012800	NONE
BAMPTON WWTW	RIVER BATHERM	SS9541021790	SCREENING
BARNHILL PUMPING STATION	GROUNDWATE R VIA INFILT SYSTEM	SX9273098460	NONE
BARRINGTON STREET CSO	RIVER LOWMAN	SS9577012580	SCREENING
BARTON HILL/BRUNSWICK CSO	DAWLISH WATER (S)	SX9591076670	SCREENING
BATHILL PSEO	STREAM (S)	ST0361107084	NONE
BELLE PARADE CSO	STREAM (S)	SS8448600412	NONE
BESSOM BRIDGE PUMPING STATION	WIMBLEBALL LAKE	SS9740031871	NO TREATMENT REQUIRED - GOOD ENGINEERING DESIGN

Name	Receiving Environment	NGR	Treatment (if applicable)
BICKLEIGH STW	TRIB OF RIVER EXE	SS9401007000	NONE
BLUE BALL PUMPING STATION	TRIB OF RIVER CLYST	SX9686090930	NO TREATMENT REQUIRED - GOOD ENGINEERING DESIGN
BONHAY PARK CSO	RIVER EXE	SX9140092310	SCREENING
BONHAY ROAD CSO	TIDAL RIVER EXE(E)	SX9783081900	SCREENING
BOOBERY ROAD COMBINED SEWER OVERFLO	TRIB OF SPRATFORD STREAM	ST0303014370	NONE
BRAMPFORD SPEKE LAKE BRIDGE PSEO	STREAM (S)	SX9275097812	NONE
BRIDGE HOUSE CSO	RIVER EXE	SS9532012540	NONE
BRIDGETOWN WWTW PS	RIVER EXE	SS9233033200	UNSPECIFIED
BRITTON STREET PSEO	RIVER BATHERN	SS9593022131	UNSPECIFIED
BROADCLYST (SIDE) PUMPING STATION	RIVER CLYST VALLEY VIA SWS	SX9851097400	NO TREATMENT REQUIRED - GOOD ENGINEERING DESIGN
BROMPTON REGIS STW	PULHAM RIVER(S)	SS9553031200	UNSPECIFIED
BROOK COTTAGE PUMPING STATION	NADDER BROOK	SX8911093440	SCREENING
BROOK HOUSE SSO	DAWLISH WATER (S)	SX9544076790	SCREENING
BRUSHFORD WWTW	RIVER BARLE	SS9264025890	SCREENING
BUCKLAND WASTEWATER TREATMENT WORKS	ENGLISH CHANNEL (COASTAL)	SX9606071430	SCREENING
BUDDLE LANE CSO	RIVER EXE VIA SWS	SX9300090670	NONE
BULLEN STREET COMBINED SEWER OF	TRIB OF THE RIVER EXE VIA SWS	SS9259002110	NONE
BULLER ROAD CSO	STREAM (S)	SS8448600412	NONE
BURLESCOMBE WWTW	FENACRE WATER	ST0653016980	SCREENING
BURNTHOUSE LANE CSO	NORTHBROOK VIA SWS	SX9429091240	SCREENING
CADELEIGH STW	UNNAMED WATERCOURSE(S)	SS9153008120	UNSPECIFIED
CENTRAL STATION YARD CSO	HIGHER LEAT VIA SWS	SX9147092500	SCREENING
CHERITON BISHOP PSCSO/EO	FORD BROOK (S)	SX7730093000	NONE
CHERITON BISHOP STW	FORD BROOK(S)	SX7757093550	SCREENING
CHERITON FITZPAINE WWTW	TRIBUTARY OF HOLLY WATER	SS8580006150	SCREENING
CHURCH LANE COMBINED SEWER OVERFLOW	TRIB OF RIVER CREEDY VIA SWS	SS8448000410	NONE
CHURCH ROAD CSO	ALPHIN BROOK	SX9176090270	SCREENING
CHURCH ROAD CSO	COFTON STREAM(S)	SX9718280629	SCREENING
CHURCH ROAD CSO	CRANNY BROOK	SY0416097130	SCREENING
CHURCH ROAD JCT OF CECIL ROAD CSO	RIVER EXE VIA SWS	SX9299090670	NONE
CHURCH STREET COMBINED SEWER OVERFLOW	TRIB OF RIVER CREEDY (SWS)	SS8448000410	NONE

Name	Receiving Environment	NGR	Treatment (if applicable)
CHUTE STREET CSO	RIVER EXE VIA SWS	SX9223091890	NONE
CLIFTON ROAD/JCT ALBERT ROAD CSO	RIVER EXE VIA SWS	SX9223091880	NONE
CLYST HONITON PUMPING STATION	RIVER CLYST	SX9865093690	SCREENING
COACH ROAD CSO	STREAM (S)	SS9586402917	NONE
COCKWOOD PSEO	COFTON STREAM(S)	SX9756680731	SCREENING
COFTON PSCSO/EO	COFTON STREAM(S)	SX9711880605	SCREENING
COLLETON GROVE CSO	RIVER EXE VIA SWS	SX9223091890	NONE
CORNER LANE PUMPING STATION	TRIBUTARY OF SPRATFORD STREAM	ST0074012820	SCREENING
COUNCIL YARD PSCSO/EO	TRIB RIVER CREEDY (S)	SS8447000390	NONE
COWLEYMOOR ESTATE CSO	TRIB OF RIVER LOWMAN VIA SWS	SS9610012990	NONE
CULMSTOCK SEWAGE TREATMENT WORKS	RIVER CULM	ST0992013680	SCREENING
DAWLISH (ROYAL HOTEL) PS	DAWLISH WATER(C)	SX9636076620	NONE
DAWLISH BREAKWATER SSO	LYME BAY (C)	SX9648076510	SCREENING
DAWLISH SSO (BROOK STREET)	DAWLISH WATER(S)	SX9567076740	SCREENING
DAWLISH WARREN ROAD PS	SHUTTERTON BROOK(S)	SX9760478924	SCREENING
DAWLISH WARREN ROAD PS	SHUTTERTON BROOK(S)	SX9760678925	SCREENING
DIX'S FIELD CSO	RIVER EXE VIA SW SEWER	SX9224091880	NONE
DUKE STREET PUMPING STATION	CULLOMPTON MILL LEAT	ST0238006730	SCREENING
DULFORD PSCSO/EO	WEAVER (S)	ST0697005960	NONE
DULVERTON WWTW	RIVER BARLE	SS9158027280	SCREENING
DUNKESWELL PS	DUNKESWELL STREAM(S)	ST1426007700	SCREENING
DUNKESWELL STW	RIVER MADFORD (S)	ST1519008580	SCREENING
DUNSFORD ROAD CSO	RIVER EXE VIA SWS	SX9299090670	NONE
EBFORD PUMPING STATION	RIVER CLYST (ESTUARINE)	SX9758087940	SCREENING
ELM GROVE CSO	LYME BAY (C)	SX9679077050	SCREENING
EXE BRIDGE PS	RIVER EXE(S)	SS9296024420	NONE
EXE STREET CSO	HIGHER LEAT	SX9146092510	SCREENING
EXELEIGH PSEO	RIVER EXE (E)	SX9756082430	NONE
EXETER (COUNTESS WEAR) SSO	RIVER EXE ESTUARY(E)	SX9479089240	SCREENING
EXETER (COUNTESS WEAR) SSO	RIVER EXE ESTUARY(E)	SX9497089050	SCREENING
EXETER BOWLING CLUB CSO	RIVER EXE VIA SWS	SX9223091890	NONE
EXETER COLLEGE CSO	HIGHER LEAT VIA SW SEWER	SX9147092500	SCREENING
EXETER ROAD CSO - EXMOUTH	WITHYCOMBE BROOK	SX9997082010	SCREENING

Name	Receiving Environment	NGR	Treatment (if applicable)
EXETER ROAD PUMPING STATION	COTTEY BROOK	SS9492011640	NO TREATMENT REQUIRED - GOOD ENGINEERING DESIGN
EXFORD STW	RIVER EXE	SS8567038160	
EXFORD STW PSEO	RIVER EXE (S)	SS8567038160	NONE
EXMOUTH SEWAGE TREATMENT WORKS	LYME BAY(C)	SY0379079190	SCREENING
EXTON NORTH PS	RIVER CLYST (ESTUARINE)	SX9769086890	SCREENING
EXTON SOUTH PUMPING STATION	WOODBURY BROOK (ESTUARINE)	SX9809086240	SCREENING
FERRY ROAD PUMPING STATION	RIVER EXE	SX9623088140	NO TREATMENT REQUIRED - GOOD ENGINEERING DESIGN
FIRST AVENUE SERVICE LANE CSO	NORTH BROOK VIA SWS	SX9480092300	NONE
FOLLET ROAD CSO	RIVER EXE (E)	SX9622088140	SCREENING
FORD BARTON PSEO	STREAM (S)	SS9132318219	NONE
FORE STREET CSO	KNOWLE STREAM	SY0649081880	NONE
FORGE WAY CAR PARK CSO	MILL STREAM (S)	ST0227907436	NONE
GENERALS LANE PUMPING STATION	S/WATER SYSTEM TO EXE ESTUARY	SX9766081850	SCREENING
GOLD STREET CSO	RIVER LOWMAN	SS9576012560	NONE
GRANARY LANE (NORTH) CSO	KERSBROOK CHANNEL	SY0711082740	SCREENING
GRANARY LANE CSO	TRIB OF RIVER OTTER (S)	SY0718082270	NONE
HAM LANE CSO	WOODBURY BROOK	SY0074086930	SCREENING
HAREWOOD PSEO	SURFACE (S)	SS9680030120	NONE
HARTOPP ROAD CSO	EXE ESTUARY	SX9996081460	SCREENING
HAWKINGS WAY CREDITION CSO	TRIB OF RIVER CREEDY VIA SWS	SS8448000410	NONE
HEATH CROSS PUMPING STATION	TRIB OF RIVER CLYST	SX9882096880	NO TREATMENT REQUIRED - GOOD ENGINEERING DESIGN
HEAVITREE PLEASURE GROUND CSO	NORTH BROOK VIA SWS	SX9479092290	NONE
HEMYOCK PSCSO/EO	RIVER CULM (S)	ST1384013930	NONE
HEMYOCK STW PSEO	RIVER CULM (S)	ST1384013940	NONE
HEMYOCK WASTEWATER TREATMENT WORKS	RIVER CULM	ST1339013880	SCREENING
HESCANE PARK CSO	YEO(S)	SX7742493169	NONE
HIGH MARSH PSEO (HALF MOON VILLAGE)	RIVER CREEDY(S)	SX8967097460	SCREENING
HOLCOMBE PUMPING STATION	SHELL COVE, LYME BAY(C)	SX9608075340	SCREENING
OLCOMBE ROGUS WWTW	TRIB OF RIVER LYNER	ST0580018240	PRIMARY SETTLEMENT
HOLLOWAY STREET	RIVER EXE VIA SWS	SX9223091880	NONE
HOWELL ROAD CSO	HIGHER LEAT VIA SWS	SX9146092500	SCREENING
HUNTSHAM STW	TRIBUTARY OF RIVER LOWMAN(S)	ST0052020230	UNSPECIFIED

Name	Receiving Environment	NGR	Treatment (if applicable)
IMPERIAL ROAD TANK CSO	EXE ESTUARY	SX9986081110	SCREENING
IN FIELD R/0 11 GRANTLANDS	MILL BROOK (S)	ST0653212323	NONE
JEWSONS YARD CSO	RIVER YEO (S)	SX8474699207	NONE
JOCKEY HILL CSO	TRIBUTARY OF IVER CREEDY	SS8448000410	NONE
KENN AND KENNFORD PUMPING STATION	RIVER KENN	SX9275085270	SCREENING
LANGATON LANE CSO	PIN BROOK	SX9731094130	NONE
LARKBEARE HOUSE CSO	RIVER EXE VIA SWS	SX9223091890	NONE
LIME KILN PSEO	KERSBROOK CHANNEL	SY0722082100	SCREENING
LIME KILN TANK CSO	ENGLISH CHANNEL	SY0794081920	SCREENING
LITTLE KNOWLE CSO	KNOWLE STREAM	SY0535082260	NONE
LITTLE SILVER PUMPING STATION	RIVER LOWMAN	SS9534011980	SCREENING
LITTLE SILVER PUMPING STATION	RIVER LOWMAN	SS9544012080	SCREENING
LORDS MEADOW WWTW	RIVER YEO/RIVER CREEDY	SS8488000620	SCREENING
LORDS MEADOW WWTW	RIVER YEO	SX8475099210	
LOWER AVENUE CSO	NORTH BROOK VIA SWS	SX9479092290	NONE
LOWER MILL COMBINED SEWER OVERFLOW	RIVER BARLE	SS9125027720	NONE
LOWER NORTH STREET CSO	HIGHER LEAT VIA SW SEWER	SX9147092500	SCREENING
LYMPSTONE OUTFALL PUMPING STATION	RIVER EXE ESTUARY	SX9874083860	SCREENING
MAER PUMPING STATION & TANK CSO	ENGLISH CHANNEL	SY0111079660	SCREENING
MAER ROAD CSO EXMOUTH	LITTLEHAM BROOK	SY0107080060	SCREENING
MAGDALEN ROAD CSO	RIVER EXE VIA SWS	SX9223091880	NONE
MAGELAKE PS	RIVER CULM(S)	ST0703812505	NONE
MAIN ROAD CSO	BERRY BROOK	SX9456087320	NONE
MARINA PSEO	DAWLISH (C)	SX9712277366	NONE
MARINE PARADE CSO	KNOWLE STREAM	SY0664081860	SCREENING
MARSH GREEN WASTEWATER TRTMNT WORKS	FORD STREAM (S)	SY0419093810	SCREENING
MEADOW ROAD TANK CSO	KNOWLE STREAM	SY0597082060	SCREENING
MIDDLE MILL LANE CSO	MILL LEAT	ST0228007350	SCREENING
MILBURY LANE PUMPING STATION	TRIB OF THE BERRY BROOK	SX9483087970	SCREENING
MILBURY LANE PUMPING STATION	TRIB OF THE BERRY BROOK	SX9500088340	SCREENING
MILL RACE COMBINED SEWER OVERFLOW	MILL RACE, RIVER EXE	SX9341090620	NONE
MILL ROAD PUMPING STATION	RIVER EXE (ESTUARINE)	SX9397090120	NO TREATMENT REQUIRED - GOOD ENGINEERING DESIGN
MILL STREET COMBINED SEWER OVERFLOW	TRIB RIVER CREEDY (S)	SS8418900304	NONE
MILL STREET COMBINED SEWER OVERFLOW	TRIB OF RIVER CREEDY VIA SWS	SS8419000300	NONE

Name	Receiving Environment	NGR	Treatment (if applicable)
MILLMOOR CSO	RIVER CULM(S)	ST1007513766	NONE
MONKERTON PUMPING STATION	PIN BROOK	SX9671093970	NO TREATMENT REQUIRED - GOOD ENGINEERING DESIGN
MOOR LANE PSCSO/EO	STREAM (S)	SX9645097062	NONE
MOREBATH STW	SHUTTERN BROOK (S)	SS9535024770	UNSPECIFIED
NEWPORT PARK PUMPING STATION	TRIB OF RIVER EXE (ESTUARINE)	SX9541088990	NO TREATMENT REQUIRED - GOOD ENGINEERING DESIGN
NEWTON ST CYRES STW	(S) RIVER CREEDY	SX8885098140	SCREENING
NORTH LAWN COURT CSO	NORTH BROOK VIA SWS	SX9479092300	NONE
NORTH STREET CAR PARK CSO	TRIB OF RIVER CREEDY VIA SWS	SS8448600412	NONE
NORTHBROOK GOLF COURSE LOWER CSO	NORTHBROOK	SX9382090390	SCREENING
NORTHBROOK PARK GOLF CRSE UPPER CSO	NORTHBROOK	SX9383090400	SCREENING
O/S 25 OAK CRESCENT PSEO	TRIB OF CULM (S)	ST0310010480	NONE
O/S HONITON INN	RIVER EXE (S)	SX9254792833	NONE
OAKFORD STW	TRIB OF IRON MILL STREAM (S)	SS9115021420	UNSPECIFIED
OAKLANDS PSEO	COASTAL (C)	SX9610475854	NONE
OKEHAMPTON ROAD CSO	RIVER EXE VIA SWS	SX9299090670	NONE
OLD TIVERTON ROAD CSO	STREAM(S)	SS8448600412	NONE
OLD WOODBURY SALTERTON STW CSO	TRIB OF GRINDLE BROOK VIA SWS	SY0128089340	SCREENING
PARKLAND DRIVE PUMPING STATION	NORTHBROOK VIA SWS	SX9430091240	NONE
PATHFINDER TERMINAL PS	LILLY BROOK(S)	SX8248093950	SCREENING
PENCEPOOL FARM PUMPING STATION	TRIBUTARY OF RIVER CLYST (S)	ST0522003090	SCREENING
PENNSYLVANIA ROAD CSO	HIGHER LEAST VIA SW SEWER	SX9147092500	SCREENING
PENNYMOOR SEWAGE TREATMENT WORKS	A TRIBUTARY OF BINNEFORD WATER	SS8645011630	SCREENING
PHEAR PARK PSEO/CSO	EXE ESTUARY	SX9996081460	SCREENING
PLYMTREE STW	RIVER WEAVER	ST0406003960	PRIMARY SETTLEMENT
PLYMTREE STW	AN UNNAMED TRIB-RIVER CLYST	ST0491002790	SCREENING
POUNDSHILL PSCO/EO	STREAM	ST0606418853	NONE
PUDDINGTON STW	RIVER CREEDY	SS8360010730	NONE
QUAY HILL COMBINED SEWER OVERFLOW	HIGHER LEAT	SX9192092170	NONE
QUAY HILL CSO	HIGHER LEAT VIA SW SEWER	SX9194092150	SCREENING
R/O 13 WEST STREET CSO	RIVER BATHERN (S)	SS9546622016	NONE
R/O IMPERIAL HOTEL CSO	TADDIFORDE BROOK	SX9141093490	NONE
RAGSFIELD PSEO	TRIB OF R. CREEDY	SS8442300595	NONE
REWE WASTEWATER TREATMENT WORKS	RIVER CULM	SX9455098840	SCREENING
ROSE COTTAGE CSO	LILLY BROOK (S)	SX8228894125	NONE

Name	Receiving Environment	NGR	Treatment (if applicable)
SAMPFORD PEVERELL WWTW	SPRATFORD STREAM	ST0387013360	SCREENING
SANDFORD PUMPING STATION	THE SANDFORD STREAM (S)	SS8309502203	NONE
SANDFORD ROSE & CROWN CSO	THE SANDFORD STREAM (S)	SS8275102304	SCREENING
SANDFORD WASTEWATER TREATMENT WORKS	TRIBUTARY OF RIVER CREEDY	SS8339002240	SCREENING
SANDY BAY HOLIDAY PARK PSEO	STRAIGHT POINT (C)	SY0398079190	NONE
SANDY LANE PUMPING STATION	LYME BAY (COASTAL)	SX9736076490	SCREENING
SANDY LANE PUMPING STATION	LYME BAY (C)	SX9742076470	SCREENING
SEA LAWNS OUTFALL CSO, DAWLISH	LYME BAY(C)	SX9679077050	NONE
SEA LAWNS PUMPING STATION	LYME BAY	SX9679077050	NO TREATMENT REQUIRED - GOOD ENGINEERING DESIGN
SEARLE STREET CSO	STREAM (S)	SS8448600412	NONE
SHILLINGFORD ST GEORGE WWTW CSO	ALPHIN BROOK	SX9073087980	
SHIP INN CSO	COFTON STREAM(S)	SX9752580690	SCREENING
SHOBROOKE PS	SHOBROOKE LAKE	SS8712001320	SCREENING
SHUTE WWTW	TRIB OF RIVER CREEDY	SS8954000080	SCREENING
SHUTTERTON BRIDGE PS	SHUTTERTON BROOK(S)	SX9658078540	SCREENING
SILVERTON PUMPING STATION	SILVERTON STREAM VIA SWS	SS9527003010	SCREENING
SILVERTON WWTW	HEAL-EYE STREAM	SS9712001420	SCREENING
SLITTERCOMBE LANE PSCSO/EO	RIVER KENN(S)	SX9613083470	SCREENING
SMUGGLERS LANE PSEO	BABBACOMBE BAY(C)	SX9568074640	SCREENING
SOWDEN LANE PUMPING STATION	TRIBUTARY OF EXE ESTUARY (S)	SX9912083670	SCREENING
SPREYTON STW	COOMBE STREAM(S)	SX6985097520	SCREENING
ST MARTINS LANE CSO	STREAM (S)	SS8448500412	NONE
ST NICHOLAS CHURCH PSEO	BROCKERY RIVER (S)	SS9189725652	NONE
ST SIDWELLS SCHOOL CSO	HIGHER LEAT VIA SW SEWER	SX9147092500	SCREENING
STATION ROAD PSCSO/EO WILLAND	SPRATFORD STREAM	ST0332111417	
STATION ROAD PSEO	RIVER CREEDY(S)	SX8810098560	SCREENING
STOKE CANON PSEO	R CULM (S)	SX9371097598	SCREENING
STOKE MEADOW CLOSE PUMPING STATION	MINCINGLAKE STREAM VIA SWS	SX9330094620	NO TREATMENT REQUIRED - GOOD ENGINEERING DESIGN
STONEYFORD PSCSO/EO	RIVER CULM (S)	ST0287607453	SCREENING
STOODLEIGH STW	STOODLEIGH STREAM	SS9243018980	

Name	Receiving Environment	NGR	Treatment (if applicable)
SWEETBRIER LANE CSO	NORTHBROOK	SX9481092600	SCREENING
SWEETHAM SEWAGE PUMPING STATION	RIVER CREEDY(S)	SX8813098580	SCREENING
TALATON PSCSO/EO	STREAM (S)	SY0685699822	NONE
TAN LANE PUMPING STATION	TRIB OF THE ALPHIN BROOK	SX9204091350	NO TREATMENT REQUIRED - GOOD ENGINEERING DESIGN
TEDBURN ST MARY STW	LILLY BROOK(S)	SX8248093950	SCREENING
TEDBURN ST MARY STW	LILLY BROOK(S)	SX8250093940	SCREENING
TEMPLE ROAD CSO	RIVER EXE VIA SWS	SX9223091880	NONE
THE COLLEGE IDE CSO	FORDLAND BROOK	SX9001090600	SCREENING
THE GREEN TANK CSO	KNOWLE STREAM	SY0617081990	SCREENING
THE WALRONDS CSO	RIVER EXE	SS9526011910	NONE
THORNTON HILL CSO	HIGHER LEAT VIA SWS	SX9147092500	NONE
THORVERTON WWTW	(S) RIVER EXE	SS9359001680	SCREENING
TIVERTON STW	RIVER EXE	SS9530010300	SCREENING
TOPSHAM ROAD JCT ROBERS ROAD CSO	RIVER EXE VIA SWS	SX9223091890	NONE
TURLAKE SPS	TRIB OF R EXE	SX9049296109	
UFFCULME PUMPING STATION	RIVER CULM	ST0632011960	SCREENING
UFFCULME WWTW	RIVER CULM	ST0622011860	SCREENING
UPLOWMAN STW	UPLOWMAN STREAM	ST0132015270	SCREENING
VIADUCT HIGH LEVEL STORM TANK CSO	DAWLISH WATER(C)	SX9630076660	SCREENING
WAR MEMORIAL CSO	RIVER CULM (S)	ST0973713696	NONE
WASHFIELD STW	TRIBUTARY OF RIVER EXE(S)	SS9353015050	UNSPECIFIED
WEAVER CRESCENT CSO	RIVER EXE	SS9481013410	SCREENING
WELL STREET CSO	HIGHER LEAT VIA SW SEWER	SX9147092500	SCREENING
WEST CLIFF COMBINED SEWER OVERFLOW	DAWLISH WATER	SX9569076710	SCREENING
WESTEXE PUMPING STATION	RIVER EXE	SS9532012010	SCREENING
WESTWOOD PSEO	TRIB RIVER YEO (S)	SS8225800129	NONE
WHIDDON DOWN STW	FINGLE BROOK(S)	SX6929092440	SCREENING
WILLAND WASTEWATER TREATMENT WORKS	TRIB OF RIVER CULM	ST0419010600	SCREENING
WILLAND WASTEWATER TREATMENT WORKS	TRIB OF RIVER CULM	ST0420010160	SCREENING
WINSFORD PSCSO/EO	RIVER EXE(S)	SS9072034830	SCREENING
WITHYBRIDGE PUMPING STATION	RIVER CLYST	SX9747095730	NO TREATMENT REQUIRED - GOOD ENGINEERING DESIGN
WOODBURY WWTW	WOODBURY BROOK	SX9979086780	SCREENING
WOODLAND AVE CSO	STREAM DIS TO LYME BAY (S)	SX9509074280	SCREENING
WWTW AT BRADNINCH	RIVER CULM	ST0057003310	SCREENING
YEOFORD WASTEWATER TREATMENT WORKS	RIVER YEO	SX7894098740	SCREENING

13 Spill frequencies and durations for intermittent discharges into the Exe Estuary and Lyme Bay West in 2020

Intermittent discharge	Permit Number	Spill Frequency Threshold	Spill Frequency (>threshold)	Total spill duration (hrs)	Action
Sandy Lane Lf Spst_pscsoeo_dawlish	201966	5	**56**	63	SOAF investigation in 2023
Viaduct Sps_pscsoeo_dawlish	200824/PC/01	5	**20**	38	-
Cofton Sps_pscsoeo_dawlish	202627	14	**45**	384	SOAF investigation in 2023
Ship Inn_cso_cockwood	202630	14	11	1	-
Warren Road Sps_pscsoeo_dawlish	202631	14	**54**	71	SOAF investigation in 2022
Bonhay Rd_cso_starcross	202625	14	**20**	129	-
Slittercombe Spst_pscsoeo_kenton	202626	14	11	55	-
Exminster Spst_pscsoeo_exminster	201580	40	**47**	155	-
Church Road_cso_alphington	201933	40	23	6	-
Holloway St_cso_exeter	201925	40	**74**	127	-
Lwr North St I_cso_exeter	201373	40	**70**	141	-
Dunsford Rd_cso_exeter	201932	40	32	43	-
Mill Race/river Exe_cso_exeter	201896	40	33	85	-
Northbrook Golf Course Upper_cso_exeter	201914	40	20	23	-
Countess Wear Stw_so_exeter	202475	40	23	66	-
Countess Wear Stw_sso_exeter	202475	40	**65**	202	UV treatment in 2018
Follet Rd_cso_exeter	201636/CS/01	40	28	14	-
Odams Wharf Sps_pscsoeo_ebford	202365	40	**164**	404	SOAF investigation in 2021
Exton North Sps_pscsoeo_exmouth	203229	40	**146**	2003	SOAF investigation in 2022
Ham Ln_cso_woodbury	201815	40	**53**	97	SOAF investigation in 2021
Exton South Sps_pscsoeo_exmouth	203230	40	**47**	451	SOAF investigation in 2022
Lympstone Outfall Sps_pscso_lympstone	202165	14	**24**	22	SOAF investigation in 2021
Exeter Rd_cso_exmouth	200128/CS/01	14	**66**	56	SOAF investigation in 2023
Hartop Road_pscsoeo_exmouth	200122/CS/01	14	**38**	81	SOAF investigation in 2023

Spill frequency (SF) trigger permit (spills per year as 10 year averages: 40 spills for water bodies; 14 spills for shellfish waters; 5 spills for bathing waters - per bathing season) (SWW, 2021a).

Intermittent discharge	Permit Number	Spill Frequency Threshold	Spill Frequency (>threshold)	Total spill duration (hrs)	Action
Imperial Rd - Tank_cso_exmouth	200123/CS/01	5	**14**	103	-
Maer Rd Sps_cso_exmouth	200125/CS/01	5	**62**	858	Investigation in 2021 for amp7 improvements
Royal Hotel Sps_pseo_dawlish	201450	5	1	1	-
Piermont Pl/jubilee Bridge_cso_dawlish	201449	5	**7**	3	-
Barton Hill/brunswick Pl_cso_dawlish	200823/CS/01	5	**25**	14	SOAF investigation in 2023
Brook St Manor Gardens_cso_dawlish	200821/CS/01	5	**33**	11	AMP7 -reduction to 2 significant spills scheme in 2021
Brook House_cso_dawlish	200820/CS/01	5	1	2	-
Teignmouth Road_pscsoeo_holcombe	202110	5	**56**	703	NOT designed to meet bw Directive.
Smugglers Lane Sps_pscsoeo_dawlish	203688	5	**57**	200	SOAF investigation in 2023
Woodland Av_cso_holcombe	202488	5	**33**	54	-
Railway Station Car Park_cso_teignmouth	203349	5	**8**	13	-
Ilsham Valley Spst_pscsoeo_torquay	200977	5	**123**	1706	SOAF investigation in 2022 Hopes Nose

Spill frequency (SF) trigger permit (spills per year as 10 year averages: 40 spills for water bodies; 14 spills for shellfish waters; 5 spills for bathing waters - per bathing season) (SWW, 2021a).

14 Estimated mean levels of pathogens in fresh farmyard manure and slurry

Pathogen name	Maximum Levels of pathogens in fresh FYM&S			Unit[a]	Country	Reference
	Cattle	Pig	Sheep			
Cryptosporidium parvum	2.7×10^2 to 3.5×10^3	3×10^2 to 3.6×10^3	5.3×10^1 to 2.5×10^2	Oocysts g^{-1}	UK	(Hutchison et al., 2004)[b]
Mycobacterium bovis	6.5×10^3			CFU ml^{-1}	Ireland	(Scanlon and Quinn, 2000)
MAP	3×10^5			CFU g^{-1}	USA	(Bonhotal et al., 2011)
Salmonella spp.	3.9×10^4 to 5.8×10^5	9.6×10^3 to 7.8×10^4	1.1×10^3 to 2×10^3	CFU g^{-1}	UK	(Hutchison et al., 2004)[b]
Listeria monocytogenes	1.5×10^4 to 4.2×10^5	4.6×10^4 to 9.7×10^5	4.5×10^2 to 1.7×10^3	CFU g^{-1}	UK	(Hutchison et al., 2004)[b]
Clostridium spp.	$10^{4.95}$	$10^{5.28}$		CFU g^{-1}	Italy	(Costa et al., 2017)
		1.0×10^5 to $1.0 \times 10^{5.5}$		CFU g^{-1}	Ireland	(Mccarthy et al., 2013)
	1.0×10^4 to $1.0 \times 10^{4.6}$			CFU g^{-1}	Sweden	(Bagge et al., 2005)
Clostridium spp. (combined)	1.0×10^4 to $1.0 \times 10^{4.95}$	1.0×10^5 to $1.0 \times 10^{5.5}$		CFU g^{-1}		
E. coli	$5.1 \times 10^4 \pm 4.5 \times 10^4$	$3 \times 10^4 \pm 7.1 \times 10^3$		CFU g^{-1}	France	(Jaffrezic et al., 2011)
		$1.0 \times 10^{3.8}$ to $1.0 \times 10^{5.5}$		CFU g^{-1}	Ireland	(Mccarthy et al., 2013)
E. coli (combined)	0.6×10^4 to 9.6×10^4	$1.0 \times 10^{3.8}$ to $1.0 \times 10^{5.5}$		CFU g^{-1}		
E. coli O157	2.9×10^6 to 2.6×10^8	6.9×10^4 to 7.5×10^5	1.1×10^4 to 4.9×10^4	CFU g^{-1}	UK	(Hutchison et al., 2004)[b]

Pathogen name	Maximum Levels of pathogens in fresh FYM&S			Unit[a]	Country	Reference
	Cattle	Pig	Sheep			
Campylobacter spp.	7.6×10^3 to 1.5×10^5	1.9×10^3 to 1.5×10^4	8.6×10^2 to 2.1×10^3	CFU g^{-1}	UK	(Hutchison et al., 2004)[b]

15 The Storm Overflow Assessment Framework (SOAF)

Stage 1 – Spills are counted using Event Duration Monitoring (EDM) and above a threshold spill number (e.g. 60 per year) an outfall is highlighted as needing investigation. If the reporting period included exceptional rainfall, then data from more typical years are sought. Subsequent investigations check for possible blockages or leaks and whether the hydraulic capacity of the system is sufficient for heavy (storm-related) rainfall.

Stage 2 – The environmental and aesthetic impact of the outfall is determined. The aesthetic assessment covers visibility and prevalence of sewage litter and sewage fungus. The environmental assessment compares the classification of aquatic invertebrates gathered upstream and downstream from the outfall (classification is performed using the River Invertebrate Classification Tool) (WFD UKTAG, 2008). If no invertebrate monitoring data are available, water quality modelling is used for environmental assessment.

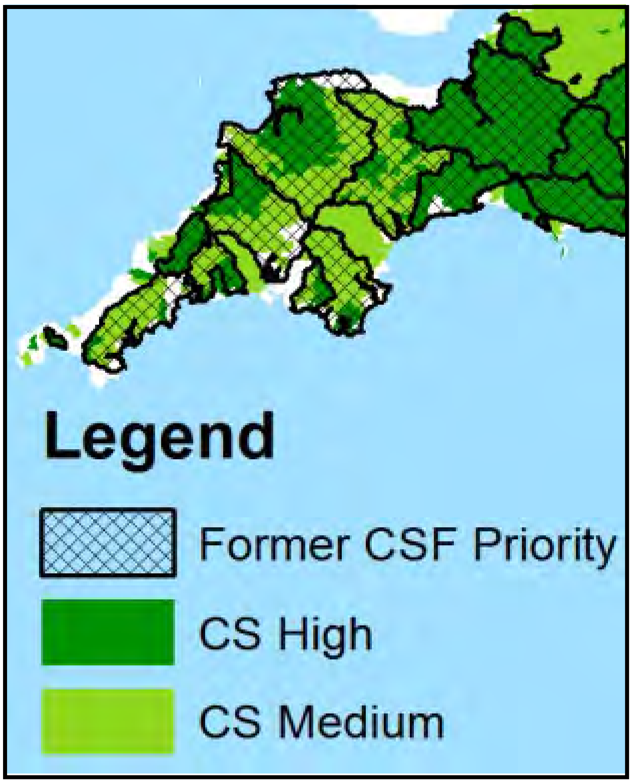
Stage 3 – Assess improvement options including a cost benefit analysis. If any of the methods applied in Stage 2 show an environmental impact, or if the outfall is situated in an urban area, then an economic assessment is made of overflow improvement.

Stage 4 – A decision is made based on the cost benefit results, with no further action being taken if the cost is disproportionate compared to the environmental benefits.

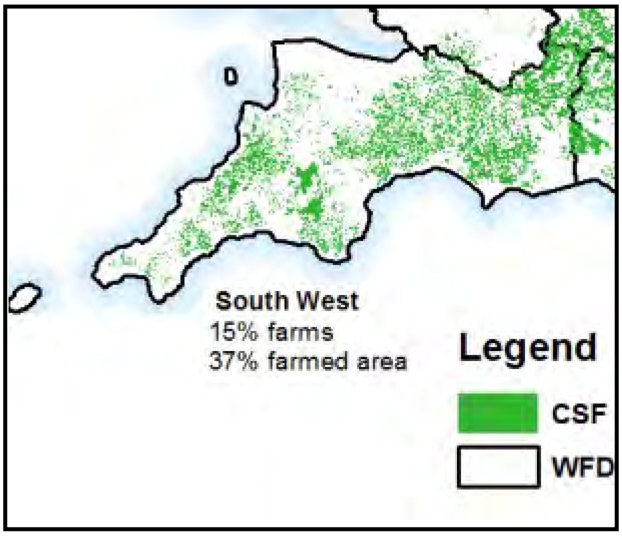
Stage 5 – The most cost beneficial solution is delivered to reduce environmental impact and/or reduce the frequency of discharges.

16 Catchment Sensitive Farming (CSF) Priority Catchments in SW England

Appendix 11.1: Extent of Countryside Stewardship High and Medium Priority Areas for Water and former CSF Priority Catchments in SW England



Appendix 11.2: Extent of CSF engagement across WFD River Basin Districts, expressed in terms of total farm numbers and total farmed area in SW England



17 Twenty most heavily applied pesticides in the South West Water Ltd. region in 2011

(from Townsend et al., 2018)

Ranking	Pesticide	Category	Tonnes applied
1	Glyphosate	Herbicide	66.7
2	MCPA	Herbicide	59.3
3	Chlormequat	Crop growth promotor	47.7
4	Mecoprop/Mecoprop-P	Herbicide	29.2
5	Chlorothalonil	Fungicide	27.5
6	Pendimethalin	Herbicide	26.9
7	Prosulfocarb	Herbicide	23.4
8	Triclopyr	Herbicide	17.2
9	MCPB	Herbicide	14.9
10	Chlorotoluron	Herbicide	12.6
11	Prothioconazole	Fungicide	10.1
12	Asulam	Herbicide	9.4
13	2,4-D	Herbicide	8.3
14	Fluroxypyr	Herbicide	7.1
	Propamocarb	Fungicide	7.1
15	Hydrochloride		
16	Clopyralid	Propamocarb	5.7
17	Mancozeb	Fungicide	5.5
18	Spiroxamine	Fungicide	5.0
19	Epoxyconazole	Fungicide	4.4
20	Flufenacet	Herbicide	4.4

18 Dissolved oxygen standards required by the EC Shellfish and Bathing Water Directives

EC Directive	DO Standard	Compliance statistic
Shellfish Waters Directive	70%	Mean, Imperative (I) standard
	60%	Minimum, Imperative (I) standard
	80%	5%ile, Guide (*G*) value
Bathing Water Directive	80–120%	10%ile, Guide (*G*) value
Urban Waste Water Treatment Directive (CSTT guidelines)	7.0 mg l^{-1}	Median (in coastal waters a change of <0.5 mg l^{-1} assumed to have no adverse effect. In estuaries a change of <1.0 mg l^{-1} assumed to have no adverse effect

19 Guidance: Sewage sludge in agriculture: code of practice for England, Wales and Northern Ireland

Guidance on Potentially Toxic Elements (PTE) in arable soil

	Max permissible conc. in soil at set pH (mg/kg dry solids)				Max permissible annual rate of PTE addition over 10 years (kg/ha)
pH	5<5.5	5.5<6.0	6.0-7.0	>7.0	
Zinc	200	200	200	300	15
Copper	80	100	135	200	7.5
Nickel	50	60	75	110	3

	Max permissible conc. in soil at set pH (mg/kg dry solids)	Max permissible annual rate of PTE addition over 10 years (kg/ha)
pH	≥5	
Cadmium	3	0.15
Lead	300	15
Mercury	1	0.1
Chromium	400	15
Molybdenum	4	0.2
Selenium	3	0.15
Arsenic	50	0.7
Fluoride	500	20

Guidance on Potentially Toxic Elements (PTE) limits in soil used as grassland

	Maximum permissible concentration of PTE in soil (mg/kg dry solids)			
pH	5<5.5	5.5<6.0	6.0-7.0	>7.0
Zinc	200	200	200	300
Copper	130	170	225	330
Nickel	80	100	125	180

	Maximum permissible concentration of PTE in soil (mg/kg dry solids)
pH	≥5
Cadmium	3
Lead	300
Mercury	1.5
Chromium	600
Molybdenum	4
Selenium	5
Arsenic	50
Fluoride	500

For lead, cadmium and fluoride, you can apply no more than 3 times the average annual limit of PTE in a single year. This is to control how much of these elements your livestock can ingest.

Guidance on when you can use treated sludge:

On growing crops	Restrictions
Cereals, oil seed rape	No restrictions
Grass	No grazing or harvesting within 3 weeks of use
Turf	Not less than 3 months before harvest
Fruit trees	Not less than 10 months before harvest

Before planting crops	Restrictions
Cereals, grass, fodder, sugar beet, oilseed rape, fruit trees	No restrictions
Soft fruit and vegetables	Not less than 10 months before harvest
Potatoes	Not less than 10 months before harvest.
Nursery stock	Not on land that's used for a cropping rotation

Guidance on protecting water

- Prevent run off if the soil is dry, or if clay soils are at, or close to field capacity.
- Prevent liquid sludge from leaching through permeable soils and polluting groundwater and land drains.
- Don't store or apply sludge close to water supply sources.
- Use good farming practices to reduce the risks of water pollution. For example, you can reduce the risk of nitrogen getting into water supplies by adjusting the timing and rates of application according to the demands of the crop.

20 Pharmaceutical concentrations in µg/L in effluent from Countess Weir Sewage Treatment Works in 2010/11

Pharmaceutical	01/06/2010	07/07/2010	12/08/2010	28/09/2010	17/10/2010	24/11/2010	09/12/2010	25/01/2011	04/02/2011	17/03/2011	27/04/2011	18/05/2011	20/06/2011	13/07/201
Non Steroidal Anti-Inlfammatory Drugs (NSAIDS)														
Ibuprofen	0.0770	0.0270	0.0180	0.0100	0.0650	0.1750	0.2010	0.1770	0.1150	0.2530	0.0100	0.0100	0.0170	0.0100
Diclofenac												0.1300	0.0640	
Antibiotics														
Erythromycin	0.9150	0.7790	0.1510	0.4270	0.4810	0.2170	1.0700	0.6240	0.4790	0.2490	0.1700	0.4400	0.2100	0.1300
Ofloxacin	0.0600	0.1080	0.0800	0.0440	0.0370	0.0150	0.0950	0.0490	0.0340	0.0430	0.0510	0.1200	0.0510	0.0340
Oxytetracycline	0.5360	6.0000	0.4660	0.3150	0.2630	0.1750	0.5350	0.4560	0.3350	0.5760	0.3000	0.2200	0.2700	0.2700
Anti-Tension/Depression														
Propranolol	0.1140	0.1860	0.1990	0.1090	0.1270	0.0350	0.1350	0.0750	0.0750	0.1570	0.0800	0.1200	0.0720	0.2000
Fluoxetine	0.0640	0.0470	0.0510	0.0100	0.0240	0.0160	0.0300	0.0180	0.0280	0.0350	0.0210	0.0360	0.0330	0.0370
Hormones														
Salicylic Acid	0.4300	0.2770	0.2310	0.2410	0.4790	0.2120	0.3540	0.7300	0.1190	0.5800	0.0690	0.2100		0.2200
Estrone	0.002	0.002	0.002	0.0057	0.0046	0.0034	0.0045	0.0051	0.0022	0.0055	0.0004	0.0016	0.0064	0.0020
Estradiol		0.000	0.002	0.0026	0.0003	0.0011	0.0008	0.0013	0.0005	0.0007	0.0002	0.0007	0.0008	0.0002
Ethynylestradiol	0.001	0.001	0.001	0.0004	0.0002	0.0012	0.0014	0.0018	0.0018	0.0008	0.0005	0.0037	0.0014	0.0001

21 Pharmaceutical, veterinary medicine (and other contaminant) concentrations in ng/L in the River Exe and Exe Estuary in June 2020

Mean river flow upstream of Station 7 Trews Weir (taken from Thorverton Weir Station 3) = 16.125 m^3/sec; Mean river flow downstream of Trews Weir = 25 m^3/sec.
River flow was normal in the Exe despite heavy rainfall in the previous week
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/895422/Rainfall_and_river_flow_summary_17_to_23_June_2020.pdf
Tidal stations 8 to 10 were sampled on the ebb tide i.e. 2 to 3 hours after high water.#

Site	Site description	17a-Ethinylestradiol	Amitriptyline	Atenolol	Azlocillin	Bentazone	Bis (2-ethylhexyl) phthalate (DEHP)	Bisphenol-S	Butyl Phthalate (DBP)	Carbamazepine	Caffeine	Cefazolin	Ceterizine	Cimetidine	Ciprofloxacin	Citalopram	Clarithromycin
1	100 m upstream of Tiverton WWTP	ND	ND	21.08	ND	ND	ND	ND	ND	51.15	404.1	ND	70.5	ND	ND	5.416	5.416
2	100 m downstream of Tiverton WWTP	ND	1.56	23	ND	ND	ND	ND	ND	55.43	271	ND	79.44	ND	ND	7.912	7.912
3	Upstream of Thorverton Weir	ND	ND	6.271	ND	ND	ND	ND	ND	15.38	132.2	ND	18.69	ND	ND	2.59	ND
4	Furze Park, upstream of Culm confluence	ND	ND	23.46	ND	ND	ND	ND	ND	55.37	376.6	ND	79.73	ND	ND	2.53	2.53
5	Furze Park, downstream of Culm confluence	ND	ND	36.56	ND	ND	ND	ND	ND	64.45	428.9	ND	88.49	ND	ND	14.98	14.98
6	Cowley Bridge	ND	ND	ND	ND	ND	ND	ND	ND	ND	277.6	ND	ND	ND	ND	ND	ND
7	Trews Weir	ND	ND	ND	ND	ND	ND	ND	ND	5.426	420	ND	2.593	ND	ND	1.316	ND
8	Countess Weir upstream of WWTP	ND	ND	17.96	ND	ND	ND	ND	ND	11.32	956.3	ND	6.593	ND	ND	5.402	ND
9	Countess Weir downstream of WWTP	ND	ND	5.02	ND	ND	ND	ND	ND	11.83	205.9	ND	5.993	ND	ND	3.274	ND
10	Starcross	ND	2.81	21.56	ND	ND	ND	ND	ND	59.95	457.4	ND	94.6	ND	ND	7.124	7.124

Site	Site description	Cotinine	Desvenlafaxine	Diazepam	Diclofenac	Diltiazem	Enrofloxacin	Erythromycin	Fexofenadine	Fluoxetine	Gabapentin	Hydrocodone	Imazalil	Ketoconazole	Ketotifen	Lidocaine	Lincomyacin
1	100 m upstream of Tiverton WWTP	48.42	97.04	ND	ND	2.788	ND	22.67	199.2	ND	998.4	4.605	ND	ND	ND	15.48	ND
2	100 m downstream of Tiverton WWTP	40.42	99.21	ND	ND	3.29	ND	21.49	199.2	ND	864.4	ND	ND	ND	ND	15.28	ND
3	Upstream of Thorverton Weir	14.98	29.7	ND	ND	1.749	ND	12.53	34.75	ND	190.6	ND	ND	ND	ND	4.2	ND
4	Furze Park, upstream of Culm confluence	41.24	114.2	ND	ND	3.385	ND	27.99	194.2	ND	1045	9.567	ND	ND	ND	14.9	ND
5	Furze Park, downstream of Culm confluence	47.42	131.5	ND	ND	5.461	ND	35.9	246.7	ND	1317	11.05	ND	ND	ND	19.7	ND
6	Cowley Bridge	13.35	ND	ND	ND	2.127	ND	ND	5.37	ND	ND	ND	ND	ND	ND	ND	ND
7	Trews Weir	25.42	ND	ND	ND	ND	ND	ND	6.146	ND	31.29	8.511	ND	ND	ND	ND	ND
8	Countess Weir upstream of WWTP	38.93	13.37	ND	ND	ND	ND	ND	27.75	ND	245.5	6.935	ND	ND	ND	ND	ND
9	Countess Weir downstream of WWTP	7.238	16.45	ND	ND	ND	ND	ND	17.11	ND	126.2	5.301	ND	ND	ND	5.117	ND
10	Starcross	50.51	109.2	ND	ND	3.484	ND	27.15	220.5	ND	1779	6.458	ND	ND	ND	17.25	ND

22 Prioritisation of veterinary medicines – compounds considered to have the greatest potential for environmental impact (Group 1)

Table adapted from Boxall et al. (2002)
Priority class abbreviations: HP-CIA = Highest Priority Critically Important Antibiotics (VMD, 2020); PS = Priority Substance (2008/105/EC).
Target group abbreviations: H = herd animals; I = individual food production animals; A = aquaculture; C = companion animals; n/a = not applicable.

Rank (use)	Veterinary medicine	Category	Priority class	Target animals	Data gap - further data required			
					Use	Metabol	Aquatic	Terrestrial
1	Oxytetracycline	Antibiotic		H, A				✓
2	Chlortetracycline	Antibiotic		H			✓	✓
3	Tetracycline	Antibiotic		H			✓	✓
4	Sulphadiazine	Antibiotic		A			✓	✓
5	Trimethoprim	Antibiotic		A			✓	✓
6	Baquiloprim	Antibiotic		H		✓	✓	✓
7	Amprolium	Coccidiostat		H	✓		✓	✓
8	Clopidol	Coccidiostat		H	✓	✓	✓	✓
9	Lasalocid Sodium	Antibiotic		H	✓	✓	✓	✓
10	Maduramicin	Antibiotic	HP-CIA	H	✓		✓	✓
11	Nicarbazin	Coccidiostat		H	✓	✓	✓	✓
12	Robenidine Hydrochloride	Coccidiostat		H	✓	✓	✓	✓
13	Amoxicillin	Antibiotic		H		✓	✓	✓
14	Procaine Penicillin	Antibiotic		H		✓	✓	✓
15	Procaine Benzylpenicillin	Antibiotic		H		✓	✓	✓
16	Clavulanic Acid	Antibiotic		H		✓	✓	✓
17	Diazinon	Insecticide	Banned	H		n/a	✓	✓
18	Tylosin	Antibiotic		H			✓	✓
19	Monensin	Antibiotic		H	✓	✓	✓	✓
20	Salinomycin Sodium	Coccidiostat		H	✓		✓	✓
21	Flavophospolipol	Antibiotic		H	✓	✓	✓	✓
22	Dihydrostreptomycin	Antibiotic		H			✓	✓
23	Neomycin	Antibiotic	HP-CIA	H, C			✓	✓
24	Apramycin	Antibiotic	HP-CIA	H			✓	✓
25	Flavomycin	Antibiotic	HP-CIA	H		✓	✓	✓
26	Morantel	Anthelmintic		H	✓		✓	✓
27	Cypermethrin	Insecticide	PS	H		n/a	✓	✓
28	Flumethrin	Insecticide		H		n/a	✓	✓
29	Triclabendazole	Fungicide		H	✓		✓	✓
30	Fenbendazole	Fungicide		H	✓	✓	✓	✓
31	Levamisole	Anthelmintic		H	✓	✓	✓	✓
32	Ivermectin	Insecticide		H	✓	✓		✓
33	Cephalexin	Antibiotic		H	✓	✓	✓	✓
34	Florfenicol	Antibiotic		A	✓	n/a	✓	
35	Tilmicosin	Antibiotic		H	✓		✓	✓
36	Oxolinic Acid	Antibiotic		H	✓	n/a	✓	✓
37	Lido/Lignocaine Hydrochloride	Anaesthetic		H	✓	✓	✓	✓
38	Tiamulin	Antibiotic		H	✓	✓		✓

39	Lincomycin	Antibiotic	HP-CIA	H			✓	✓
40	Clindamycin	Antibiotic	HP-CIA	H			✓	✓
41	Nitroxynil	Anthelmintic		H	✓	✓	✓	✓
42	Enrofloxacin	Antibiotic	HP-CIA	H			✓	✓
43	Sarafloxacin	Antibiotic	HP-CIA	A		n/a	✓	
44	Dimethicone	Skin barrier		H	✓	✓	✓	✓
45	Poloxalene	Anti-bloat		H	✓	✓	✓	✓
46	Toltrazuril	Coccidiostat		H	✓	✓	✓	✓
47	Decoquinate	Coccidiostat		H	✓	✓	✓	✓
48	Diclazuril	Coccidiostat		H	✓	✓	✓	✓
49	Phosmet	Insecticide		H	✓	n/a	✓	✓
50	Piperonyl Butoxide	Anti-fly		C	✓	n/a	✓	✓
51	Amitraz	Acaricide and Insecticide		H	✓	n/a		✓
52	Deltamethrin	Insecticide		H	✓	n/a	✓	✓
53	Cypromazine	Insecticide		H	✓	n/a	✓	✓
54	Emamectin Benzoate	Insecticide		A	✓	n/a	✓	✓?
55	Antiseptics	Antiseptics		C, I	✓	✓	✓	✓
56	Immunological products	Immuno-logical		C, H	✓	✓	✓	✓

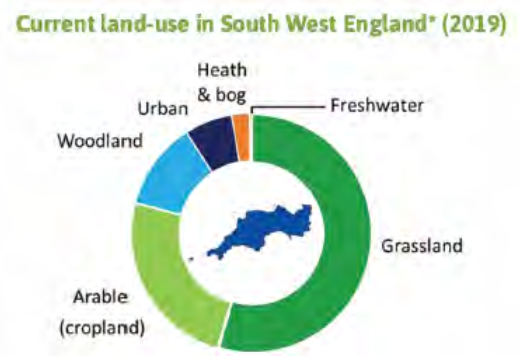
How potential future land uses may affect water quality and growth of South West aquaculture.

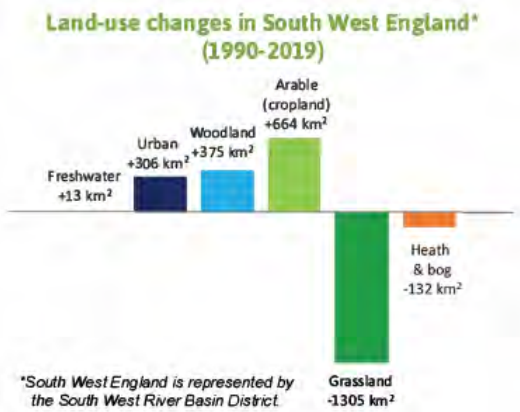
Working with stakeholders across South West England, this SWEEP project has developed a range of future land-use scenarios that will be used to model water quality in freshwater catchments (from source to sea). Findings will contribute to a better understanding of how water quality impacts on the viability and potential for growth in the South West's estuarine and marine shellfish aquaculture sectors.

The issue

Shellfish aquaculture in the South West has significant potential to boost employment, produce sustainable food, and deliver vital ecosystem services, such as habitat and fisheries enhancement, coastal protection and nutrient cycling. Despite this, it is currently an underexploited industry.

One of the key factors limiting its growth and long term viability is variable, and poor water quality, as a result of frequent agricultural and urban run-off, and sewer overflow events. These events elevate concentrations of nutrients, pesticides, suspended sediment and faecal indicator organisms (FIOs) breaching water quality standards. Climate change is further exacerbating the problem and this can result in wetter winters and more frequent flooding and storm water events.





Identifying potential future land-use management scenarios in the South West is therefore key to understanding future changes in freshwater catchment water quality, and the impact of this on the potential growth of the region's aquaculture sector. We approach this by considering both historic land-use change and key incentives driving current and future land-use decision making. The last 50 years, for example, has seen a rapid expansion and intensification of farming, with 80% of England's total land cover now under rural/agricultural land-use. The figures opposite reflect this but also show specific changes in the South West in recent decades, such as a significant decrease in grassland - a known contributing factor to higher run-off rates. Lower grade agricultural land is also being targeted for growing energy crops and direct energy generation in the form of wind and solar farms.

At the same time, drivers now exist to support the growth of England's aquaculture industry. The English Aquaculture Strategy 2020 supports a ten-fold increase in production by 2040, whilst the UK government's 25 year Environment Plan, Agriculture Act 2020 and Clean Growth Strategy 2017 encourage improvements in agricultural and land management practices that reverse environmental decline and improve water quality.

What we did

A stakeholder workshop was held in October 2020 to elicit views and insights on likely future scenarios for rural land-use management in South West England. These were used to develop realistic best and worst case land-use and water quality scenarios, over the next 10-30 years that could be used to model effects on key mariculture species.

Over 100 attendees represented views from farming, waste and water industries, conservation authorities, environmental regulators and academic researchers. 'Future outlook' video presentations were given by representatives from the Food Farming and Countryside Commission, National Farmers Union, South West Water, West Country Rivers Trust and Natural Englange.

Please see our report 'Future scenarios for modelling water quality and impacts on aquaculture in South West England' for an expanded read on the policy context, Expo workshop and stakeholder opinions.

Future land-use/management scenarios in the South West

Five future land-use/management scenarios were identified, along with a set of climate change futures. Corresponding UK National Ecosystem Assessment scenarios are given in parenthesis (UK NEA 2014)

1. Business as usual (**Go with the flow**)

The business as usual scenario represents the current expected trajectory of land-use change in South West England, based on trends from the past 30 years. Combined Sewer Overflow (CSO) rates follow current trends (CSO rates are modified according to urban development in the following land-use scenarios 2-5).

2. Extensive regenerative agriculture **(Nature at work)**

Widespread agricultural regeneration includes increased soil quality and extent of best, most versatile agricultural land and reduced agricultural run-off to water courses via best management practices.

3. Intensive agriculture **(World markets)**

Intensified agriculture (indoor livestock rearing and fodder cropping) will create pollution hotspots, compensated for to some extent by land sparing in upland areas. (Pollution hotspots may interconnect via flooding.

4. Increased renewable energy capacity **(National security)**

Opportunities to increase renewable energy capacity in South West England include bio-energy crops, solar and wind power, which will require trade-offs in terms of available land-use.

5. Strategic tree planting **(Local stewardship)**

Increased tree planting across the UK and South West England is a key component of the UK's 25 Year Environment Plan. This scenario considers the resulting changes in land-use and hydrology.

Climate change futures

Climate change futures

Climate change is likely to affect the hydro-meteorological conditions governing flow regimes, temperature and runoff in South West England. Scenarios are taken from UKCP18 and superimposed on each of the above land-use scenarios (1-5).

See Future land-use scenarios (PDF) for more detail about the above scenarios.

Next steps

These future land-use/management scenarios will feed into modelling developed to better understand the causes and effects of water quality changes on downstream stakeholders, particularly the aquaculture industry, but also water, recreation and tourism industries, which are all vital components of the South West economy.

Links

In addition to the linked-content in this report, you can also explore:

- SWEEP Aquaculture Resource Hub for more information, tools and resources.
- Published journal article: *Impacts of land use on water quality and the viability of bivalve shellfish mariculture in the UK: A case study and review for SW England*

For more information on this project please contact Project Lead and SWEEP Impact Fellow - Dr. Ross Brown (Ross.Brown@exeter.ac.uk)

About SWEEP

The South West Partnership for Environment & Economic Prosperity (SWEEP) is a partnership between the University of Exeter, the University of Plymouth and Plymouth Marine Laboratory. Funded by the Natural Environment Research Council, SWEEP brings stakeholders and experts together to solve challenges faced by those working with our natural resources.

Published November 2021

Growing aquaculture in the South West

SWEEP
Applying research to benefit our environment and economy

Future land-use scenarios (for 2050) *- affecting water quality, and potential growth of aquaculture in the South West*

Working with stakeholders from across South West England, we explored future land use scenarios for 2050 which could affect the viability of aquaculture growth in the region, through potential effects on water quality. Five possible future rural and urban land use/ management scenarios were identified, along with a set of climate change futures and the current baseline. Scenarios align with those in the UK National Ecosystem Assessment (UK NEA, 2014).

The potential effect of each scenario on the viability of estuary and marine aquaculture in SW England, is being explored through integrated, whole water catchment modelling as part of the SWEEP project 'Water quality management underpinning sustainable aquaculture and its expansion in South West England'. This involves engaging with stakeholders and policy-makers to define and investigate the trajectory and impact of future land use policies.

Analogous UK National Ecosystem Assessment scenarios are given in parentheses:

1. Business as usual (*Go with the flow*)

The business as usual scenario represents the current expected trajectory of land use change in South West England, based on trends from the past 30 years. Combined Sewer Overflow (CSO) rates follow current trends (CSO rates are modified according to urban development in the following land use scenarios 2-5).

2. Extensive regenerative agriculture (*Nature at work*)

Widespread agricultural regeneration includes increased soil quality and extent of best, most versatile agricultural land and reduced agricultural run-off to water courses via best management practices.

3. Intensive agriculture (*World markets*)

Intensification of agriculture (indoor livestock rearing and fodder cropping) will create pollution hotspots in lowland areas, compensated for to some extent by land sparing in upland areas. (Pollution hotspots may interconnect via flooding).

4. Increased renewable energy capacity (*National security*)

Opportunities to increase renewable energy capacity in South West England include bio-energy crops, solar and wind power, which will require trade-offs in available land use.

5. Strategic tree planting (*Local stewardship*)

Increased tree planting across the UK and SW England is a key component of the UK's 25 Year Environment Plan. This scenario considers the resulting changes in land use and hydrology.

Climate change futures

Climate change is likely to affect the hydro-meteorological conditions governing flow regimes, temperature and runoff in South West England. Scenarios are taken from UKCP18 and superimposed on each of the above land use scenarios (1-5).

Baseline

The scenario represents current land use and climatic/ hydrological conditions in South West England. These conditions provide a baseline against which future scenarios can be compared.

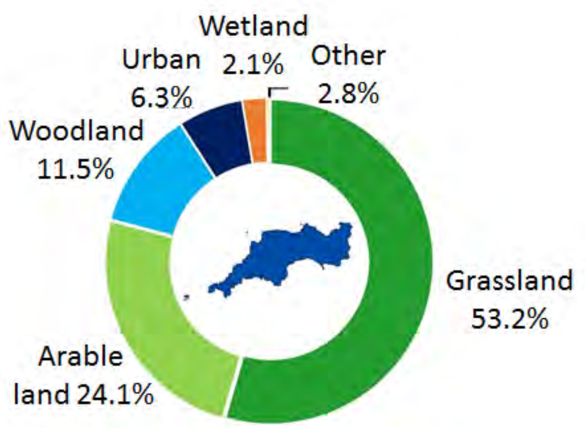
What are the key features of this scenario?

The baseline scenario represents the South West River Basin District 'as-is'. The breakdown of land use types by % of total area from CEH land cover mapping (2019) is shown below. Baseline Combined Sewer Overflow (CSO) data for 2019 and 2020 are available from Westcountry Rivers Trust (courtesy of South West Water).

Why is this important?

We have highlighted the key land use breakdown for a baseline scenario to provide a relative comparison versus future land use and land management scenarios.

We have also signposted key baseline data sets below for transparency and informed decision making.



What evidence underpins this?

Land use is based on the Centre for Ecology and Hydrology 2019 Land Cover maps (CEH, 2019). Specific crop maps are available through the CROME 2019 Crop Maps (DEFRA, 2020) and agri-chemical and slurry application is available through the CEH Land Cover Plus mapping (CEH, 2021), MANURES GIS mapping (Nicholson et al., 2016) and the British Fertiliser Manual PB209 (DEFRA, 2011). Hydrological data is available through the CEH National River Flow Archive (2021) and meteorological data is available through the UK MET Office (2018). Baseline data quantifying CSO spills in 2019 and 2020 are available from Westcountry Rivers Trust (2021).

How can we practically implement this in decision support?

Models and decision support tools can be applied using the data specified above. These data have been used in the first instance to parameterise Integrated Catchment models: INCA – Pathogens (Whitehouse, 2016); INCA – Metals (Wade, 2021); INCA –N (Wade 2015; and also a catchment-based wash-off model for pesticide risk assessment (Webber et al., 2021).

References

Centre for Ecology and Hydrology (2019). CEH Land Cover maps. URL (accessed May 2021): https://www.ceh.ac.uk/ukceh-land-cover-maps

Centre for Ecology and Hydrology (2021). CEH Land Cover plus: Fertilisers and Pesticides. URL (accessed May 2021): https://www.ceh.ac.uk/services/ceh-land-cover-plus-products-fertilisers-pesticides

Centre for Ecology and Hydrology (2021). CEH National River Flow Archive. URL (accessed May 2021): https https://nrfa.ceh.ac.uk/

Department for Environment, Food & Rural Affairs DEFRA (2011). British Fertiliser Manual PB209. URL (accessed May 2021): https://www.gov.uk/government/publications/fertiliser-manual-rb209--2

Department for Environment, Food & Rural Affairs DEFRA (2020). Crop Map of England (CROME) 2020. . URL (accessed May 2021): https://data.gov.uk/dataset/be5d88c9-acfb-4052-bf6b-ee9a416cfe60/crop-map-of-england-crome-2020

Nicholson F, Chambers B, Lord E, Bessey R, Misselbrook T (2016). Estimates of manure volumes by livestock type and land use for England and Wales. NERC Environmental Information Data Centre. (Dataset). https://doi.org/10.5285/517717f7-d044-42cf-a332-a257e0e80b5c MANURES GIS mapping

UK MET Office (2018). UK Climate Projections 2018 (UKCP018). URL (accessed May 2021): https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/about

UK National Ecosystem Assessment (2014) The UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, LWEC, UK. URL (accessed December 2020): http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx

Wade (2015). INCA-N (Integrated Catchments Model - Nitrogen dynamics) URL (accessed May 2021): https://catalogue.ceh.ac.uk/documents/imp-model-b88b-960d0c2b6b14

Wade (2021) INCA-Metals: INCA Versions and Applications URL (accessed May 2021): https://www.reading.ac.uk/geographyandenvironmentalscience/research/INCA/ges-INCA-versions-applications.aspx
Webber (2021): Southwest catchment wash off scenario exploration tool for pesticide risk assessment. URL (accessed May 2021): https://sweep.ac.uk/aquaculture-hub/#tools

Westcountry Rivers Trust (2021). Raw Sewage in our Rivers – Sewage Map. URL (accessed May 2021): https://www.theriverstrust.org/what-we-do/sewage-in-rivers/

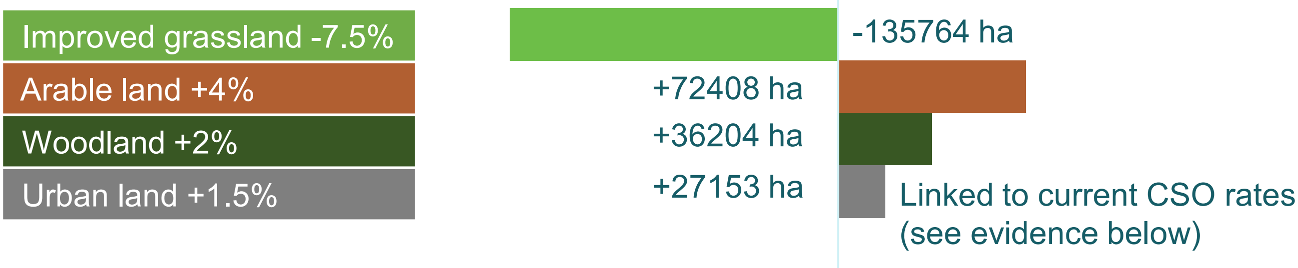
Whitehouse P (2016). INCA-Pathogens: Integrated Catchment model. URL (accessed May 2021): https://catalogue.ceh.ac.uk/documents/35f1d67e-afd1-45fa-9ded-78f00435a790

1. Business as usual

The business as usual scenario represents the current expected trajectory of land use change in South West England, based on trends from the past 30 years. Combined Sewer Overflow (CSO) spill rates follow current trends.

What are the key features of this scenario?

Expected changes in % of total land cover across the SW River Basin District :



Why is this important?

Analysis of current trends highlights a continued loss in agricultural grassland to be replaced by increasing arable land, woodland and urban areas. This will continue to affect the range and quantity of pollutants impacting watercourses in South West England. This scenario aligns with 'Go with the flow' under the UK National Ecosystem Assessment (UK NEA, 2014).

What evidence underpins this?

Changes in land use are based on extrapolation from historic changes in the CEH land cover mapping (1990-2019) projected forward (CEH, 2019). The projected change in (sub)urban land cover (6.3-7.8%) is in line with the ~20% population increase (projected by South West Water for 2039) (SWW, 2019). CSO spill rates will remain at current levels (WRT, 2021), assuming adequate storm water capacity will be provided for new developments.

How can we practically implement this in decision support?

Business as usual can be implemented through changing land uses, in line with changes in land cover specified above.

Land management is not expected to change significantly from current levels and extent of engagement (37% of farmland managed under Countryside Stewardship – employing Catchment Sensitive Farming practices).

Extent of farm engagement and stewardship across WFD River Basin Districts

References

Centre for Ecology and Hydrology (2019). CEH Land Cover maps. URL (accessed May 2021): https://www.ceh.ac.uk/ukceh-land-cover-maps

SWW (2019). Final Water Resources Management Plan 2019. URL (accessed May 2021): https://www.southwestwater.co.uk/siteassets/document-repository/environment/sww-bw-wrmp19---finalplan_aug2019.pdf

SWW (2020). Upstream Thinking 2015-2020: An overview of progress contributing to 10 years of Upstream Thinking in the South West UK. URL (accessed January 2021): https://www.southwestwater.co.uk/siteassets/document-repository/environment/j121-sww-ust-v7-290920.pdf

UK National Ecosystem Assessment (2014) The UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, LWEC, UK. URL (accessed December 2020): http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx

Westcountry Rivers Trust (2021). Raw Sewage in our Rivers – Sewage Map. URL (accessed May 2021): https://www.theriverstrust.org/what-we-do/sewage-in-rivers/

2. Extensive regenerative agriculture

Extensive regenerative agriculture will promote increased soil quality and extent of best, most versatile agricultural land and reduced agricultural run-off to water courses via best management to practices. CSO spills will be prevented for new developments and reduced by 50% for existing urban areas.

What are the key features of this scenario?

Extensive regenerative agriculture includes changes to land use resulting in increased soil quality and extent of best most versatile (BMV) agricultural land and reduced agricultural runoff and pollution of water courses through regenerative and precision farming practices.

Expected changes in % of total land cover across the SW River Basin District:

Why is this important?

The key elements of this scenario align with UK Government priorities to manage and enhance land use through Environmental Land Management Schemes (ELMS) and Nature Recovery Networks. This scenario is consistent with the 'Nature at work' scenario outlined in the UK National Ecosystem Assessment (UK NEA, 2014).

What evidence underpins this?

Regenerative and/or Catchment Sensitive Farming practices are anticipated to extend across 80% of farmland in SW catchments: e.g. cover cropping, no-tillage, waste recycling, integrated nutrient and pest management, integrating crops with trees and livestock, natural flood management . Uptake will be enabled through ELMS and Nature Recovery Networks (DEFRA, 2018; HM Gov, 2018a,b; HM Gov 2020) and by propagating best practice, profiled for farms in SW England (Agricology, 2020). This scenario (2) is a highly optimistic scenario. For example, the increase in woodland (+3%) exceeds (1) Business as usual scenario (+2%) and (5) Strategic tree planting scenario (+0.5%).

How can we practically implement this in decision support?

Land use changes can be input into decision support tools through spatially explicit or aggregated means. Soil health can be represented through adjusting soil organic carbon, hydrology and sediment parameters. Impact of Best Management Practices can be incorporated through adjusting variables representing hydrological flows, land run-off and contaminant inputs to watercourses using tools such as FarmScoper or trade-off analysis for all land use options (e.g. SW Regional Assembly, 2005). .

References

Agricology (2020). Farmer profiles. URL (accessed December 2020): https://www.agricology.co.uk/field/farmer-profiles

DEFRA (2018). Health and Harmony: the future for food, farming and the environment in a Green Brexit, February 2018. URL (accessed December 2020): https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/684003/future-farming-environment-consult-document.pdf

HM Government (2018a). A Green Future: Our 25 Year Plan to Improve the Environment. URL (accessed February 2020): https://www.gov.uk/government/publications/25-year-environment-plan

HM Government (2018b). The Future Farming and Environment Evidence Compendium. URL (accessed February 2020): https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/683972/future-farming-environment-evidence.pdfHM Government (2020). Policy paper: Nature Recovery Network (updated 26 November 2020). URL (accessed December 2020): https://www.gov.uk/government/publications/nature-recovery-network/nature-recovery-network

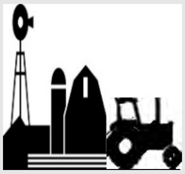
HM Government (2020). Policy paper: Nature Recovery Network. URL (accessed December 2020): https://www.gov.uk/government/publications/nature-recovery-network

Pennon (2021). Green Recovery Initiative - South West Water and Bournemouth Water. URL (accessed June 2021): https://www.pennon-group.co.uk/investor-information/green-recovery

SW Regional Assembly (2005). REVISION 2020: South West Renewable Electricity, Heat And On Site Generation Targets For 2020. Final report to the Government Office for the South West and the South West Regional Assembly. https://www.cse.org.uk/projects/view/1071

UK National Ecosystem Assessment (2014) The UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, LWEC, UK. URL (accessed December 2020): http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx

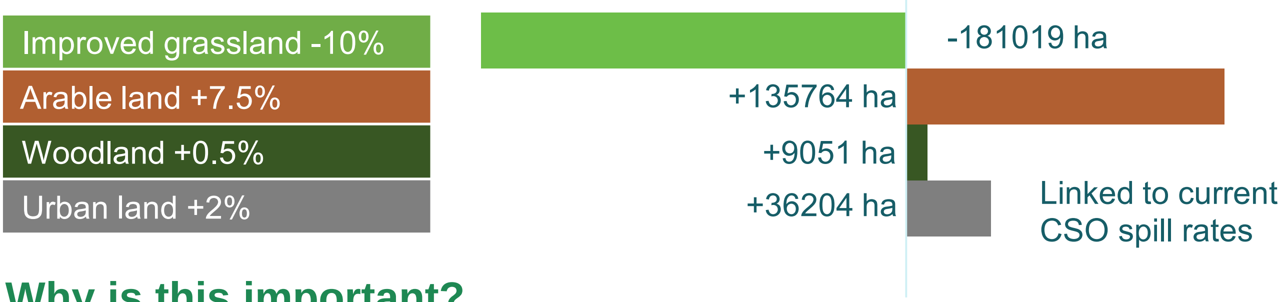
3. Intensive Agriculture



Intensification of agriculture (indoor livestock rearing and fodder cropping) will create pollution hotspots, compensated for to some extent by land sparing. (Pollution hotspots may interconnect via flooding). Combined Sewer Overflow (CSO) spill rates follow current trends.

What are the key features of this scenario?

Expected changes in % of total land cover across the SW River Basin District:



Why is this important?

This scenario is the antithesis of extensive regenerative agriculture – here ecosystem services including natural flood management and carbon capture are secondary to food production. Agriculture will intensify in the most productive lowland areas creating pollution hotspots, while less productive upland areas will be spared/neglected and allowed to re-wild. High productivity areas also include riparian areas (which could otherwise support tree planting to reduce flooding and diffuse pollution). This scenario aligns partially with the 'World markets' scenario outlined in the UK National Ecosystem Assessment (UK NEA, 2014)

What evidence underpins this?

The UK's food security is currently highly reliant on international imports (McKay et al., 2019). The vulnerability of these supply chains was highlighted following EU Exit, potentially driving growth in domestic food production. One solution is to continue to intensify agricultural production in the UK including SW England, but this has yet to be achieved in a sustainable way and current agroecosystems continue to degrade water, soil and air quality, and biodiversity (McKay et al., 2019).

How can we practically implement this in decision support?

The intensive agriculture scenario can be implemented through changing land uses, in line with changes in land cover specified above. Agriculture is expected to intensify in the most productive lowland areas, which include floodplains and riparian corridors. Upland areas are likely to be spared, neglected and potentially re-wilded. Tree felling in existing woodland will be compensated by planting of new trees; there will be a marginal increase in woodland cover to compensate for green house gas emissions and historical habitat losses. Land management is not expected to change significantly from current levels (with 37% of farmland employing Catchment Sensitive Farming practices).

References

BEIS, Department for Business, Energy & Industrial Strategy (2019). Digest of United Kingdom Energy Statistics, 2019. https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes

Defra (2019). UK's draft integrated National Energy and Climate Plan (NECP). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/774235/national_energy_and_climate_plan.pdf

Defra (2020). Defra Statistics: Agricultural Facts England Regional Profiles. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/866807/regionalstatistics_overview_20feb20.pdf

HM Government (2018a). A Green Future: Our 25 Year Plan to Improve the Environment. URL (accessed February 2020): https://www.gov.uk/government/publications/25-year-environment-plan

HM Government (2018b). The Future Farming and Environment Evidence Compendium: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/683972/future-farming-environment-evidence.pdfHM Government (2020). Policy paper: Nature Recovery Network (updated 26 November 2020). URL (accessed December 2020): https://www.gov.uk/government/publications/nature-recovery-network/nature-recovery-network

McKay DIA, Dearing JA, Dyke JG, Poppy GM, Firbank LG (2019). To what extent has sustainable intensification in England been achieved? Science of The Total Environment 648:1560-1569. https://doi.org/10.1016/j.scitotenv.2018.08.207

RSPB (2016). The RSPB's 2050 energy vision Meeting the UK's climate targets in harmony with nature. http://ww2.rspb.org.uk/Images/energy_vision_summary_report_tcm9-419580.pdf

SW Regional Assembly (2005). REVISION 2020: South West Renewable Electricity, Heat And On Site Generation Targets For 2020. Final report to the Government Office for the South West and the South West Regional Assembly. https://www.cse.org.uk/projects/view/1071

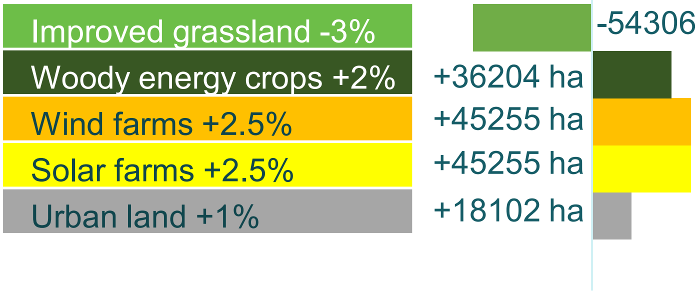
UK National Ecosystem Assessment (2014) The UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, LWEC, UK. URL (accessed December 2020): http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx

4. Increasing renewable energy capacity

Opportunities to increase renewable energy capacity in South West England include bio-energy crops, solar and wind power, which will require trade-offs in terms of available land use. CSO spills will be prevented for new developments and reduced by 50% for existing urban areas.

What are the key features of this scenario?

Expected changes in % of total land cover across the SW River Basin District:



- Short Rotation Coppice & *Miscanthus spp.*
- Wind farms co-locate with grazed pasture
- Solar farms co-locate with grazed pasture

Linked to CSO rates & Green Recovery investment to curb spills (Pennon, 2021)

Why is this important?

Significant growth in renewable energy is required to meet the UK's goal of achieving net zero greenhouse gas emissions by 2050. Key growth areas include: carbon neutral perennial biomass/energy crops; wind farms; solar farms. This scenario aligns with the 'National security' scenario outlined in the UK National Ecosystem Assessment (UK NEA, 2014) and the 'Mixed renewables scenario' from the RSPB's 2050 energy vision.

What evidence underpins this?

The UK's draft integrated National Energy and Climate Plan (NECP) calls for expansion and increased renewable energy production from onshore (and offshore) wind farms and solar farms in the next 10-30 years (BEIS, 2019; Easy, 2011; Defra, 2019). Biomass crops (mostly imported) currently generate ~50% of renewable electricity and ~80% of renewable heat in the UK. Maize is the largest domestic energy crop with 31% of UK maize (64000 ha) being grown in SW England (Defra, 2020). However, maize cultivation causes soil erosion and has a net positive carbon footprint with or without tillage. Current cultivation of perennial biomass crops elephant grass (*Miscanthus* spp. ~1500 ha) and short rotation coppice (poplar and willow ~600 ha) have significant potential to expand on low grade agricultural land and can help mitigate flood risk (Defra, 2019).

How can we practically implement this in decision support?

The renewable energy generation scenario can be implemented through changing land uses, in line with changes in land cover specified above. The geographical location of wind farms, solar farms and bioenergy crops will be dictated by exposure, aspect and soil quality respectively, which are captured in opportunity mapping targeted for each renewable energy option (SW Regional Assembly (2005). Existing woodland will be complemented (in hydrological terms) by woody energy crops; leading to an effective increase in woodland cover. Land management is expected to increase moderately from current levels (to 50% of farmland employing ELMS and CSF practices).

References:

BEIS, Department for Business, Energy & Industrial Strategy (2019). Digest of United Kingdom Energy Statistics, 2019. https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes

Defra (2019). UK's draft integrated National Energy and Climate Plan (NECP). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/774235/national_energy_and_climate_plan.pdf

Defra (2020). Defra Statistics: Agricultural Facts England Regional Profiles. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/866807/regionalstatistics_overview_20feb20.pdf

Easy et al. (2011). The Future of land use in the South West: Food, water and energy security in the face of environmental change. Big dilemmas project, University of Exeter: https://www.exeter.ac.uk/media/universityofexeter/campusservices/sustainability/pdf/Landuse_dilemmas_2012.pdf

Pennon (2021). Green Recovery Initiative - South West Water and Bournemouth Water. URL (accessed June 2021): https://www.pennon-group.co.uk/investor-information/green-recovery

RSPB (2016). The RSPB's 2050 energy vision Meeting the UK's climate targets in harmony with nature. http://ww2.rspb.org.uk/Images/energy_vision_summary_report_tcm9-419580.pdf

SW Regional Assembly (2005). REVISION 2020: South West Renewable Electricity, Heat And On Site Generation Targets For 2020. Final report to the Government Office for the South West and the South West Regional Assembly. https://www.cse.org.uk/projects/view/1071

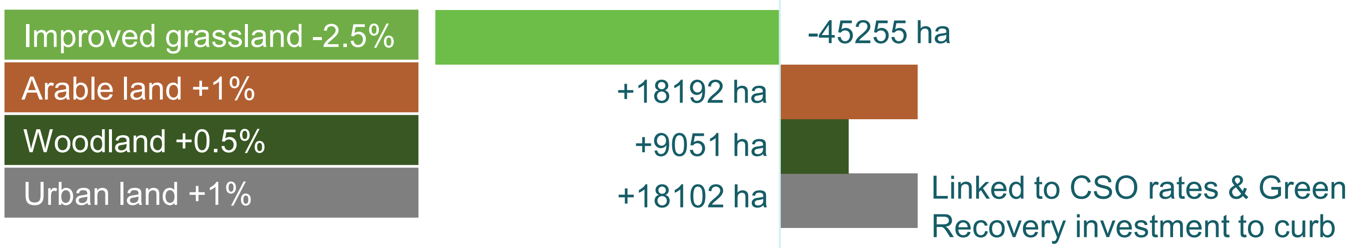
UK National Ecosystem Assessment (2014) The UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, LWEC, UK. URL (accessed December 2020): http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx

5. Strategic tree planting for water management

Tree planting across the UK and SW England is a key component of the UK's 25 Year Environment Plan. This scenario considers strategic tree planting for flood control and water quality management. CSO spills will be prevented for new developments and reduced by 50% for existing urban areas.

What are the key features of this scenario?

Expected changes in % of total land cover across the SW River Basin District:



Why is this important?

The UK's 25 Year Environment Plan (HM Gov, 2018) commits to natural woodland restoration and planting of up to 30,000 hectares of trees per year by 2025 across the UK. Furthermore, by 2050, there will be at least 12% woodland in England, according to the England Tree Action Plan (HM Gov, 2021). Strategic tree planting will contribute significantly to flood control and water quality management, as well as national efforts to promote biodiversity and reach net zero carbon emissions by 2050. This scenario aligns with the 'Local stewardship' scenario outlined in the UK National Ecosystem Assessment (UK NEA, 2014)

What evidence underpins this?

SWW aims to plant 1 million trees by 2030 as part of their Upstream Thinking Strategy (SWW, 2020). The Woodlands4Water will plant an additional 30,000 trees in three areas: the Taw Torridge catchment including the North Devon Biosphere; the Camel catchment in Cornwall; the Otter, Sid and Axe catchments and the Blackdown Hills Area of Outstanding Natural Beauty (AONB) in East Devon. This is part of the Forestry Commission and Environment Agency's £1.4 million 'Woodlands for Water' programme to protect around 160 km of river from flooding and impaired water quality by reducing surface run-off (HM Government, 2020). This scenario (5) assumes this level of strategic tree planting will increase to 2050

How can we practically implement this in decision support?

Strategic tree planting aims to contribute to flood protection and sustainable agriculture, as well as nature conservation and carbon sequestration. Based on opportunity mapping for woodland creation to meet water objectives (Forest Research, 2020), tree planting will be targeted in riparian corridors, including critical source areas (for flood control) in the uplands, lower grade farmland (identified by DEFRA, 2020) and also urban areas. A 0.5% increase in woodland cover (11.5% to 12%) across the SW River Basin District equates to +9300 ha (208860 in 2019 to 218160 ha in 2050) (CEH, 2019). Based on the Forestry Commission minimum density for native mixed woodland (1600 trees /ha), the 0.5% increase in woodland area will require a minimum of 15 million trees. Land management is expected to increase moderately from current levels (to 50% of farmland employing ELMS and CSF practices).

References

Centre for Ecology and Hydrology (2019). CEH Land Cover maps. URL (accessed May 2021): https://www.ceh.ac.uk/ukceh-land-cover-maps

Defra (2020). Defra Statistics: Agricultural Facts England Regional Profiles. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/866807/regionalstatistics_overview_20feb20.pdf

Forest Research (2020). Opportunity mapping - targeting woodland creation for water objectives. https://www.forestresearch.gov.uk/research/opportunity-mapping-woodland-for-water/

HM Government (2018). A Green Future: Our 25 Year Plan to Improve the Environment. 2020): https://www.gov.uk/government/publications/25-year-environment-plan

HM Government (2020). £3.9 million to drive innovative tree planting. https://www.gov.uk/government/news/39-million-to-drive-innovative-tree-planting

Pennon (2021). Green Recovery Initiative - South West Water and Bournemouth Water. URL (accessed June 2021): https://www.pennon-group.co.uk/investor-information/green-recovery

SWW (2020). Upstream Thinking 2015-2020: An overview of progress contributing to 10 years of Upstream Thinking in the South West UK. URL (accessed January 2021): https://www.southwestwater.co.uk/siteassets/document-repository/environment/j121-sww-ust-v7-290920.pdf

UK National Ecosystem Assessment (2014) The UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, LWEC, UK. URL (accessed December 2020): http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx

Woods4Water (2020). URL (accessed May 2021): https://www.northdevonbiosphere.org.uk/woods4water.html

Climate change futures

Climate change is likely to affect the hydro-meteorological conditions governing flow regimes, temperature and runoff in South West England. Scenarios are taken from UKCP18 and superimposed on each of the above land use scenarios (1-5).

What are the key features of this scenario?

- RCP 8.5: business as usual - emissions continue to rise throughout the 21st century.
- RCP 2.6: requires that carbon dioxide (CO2) emissions start declining by 2020 and go to zero by 2100.

Expected changes in % rainfall and temperature in summer and winter (50th percentile) across the entire SW England region by 2050:

RCP 8.5
Summer rainfall -20%
Winter rainfall +10-20%
Summer temperature +2°C
Winter temperature +1°C

RCP 2.6
Summer rainfall –10 to 20%
Winter rainfall +10%
Summer temperature +2°C
Winter temperature +1°C

Why is this important?

Observations for the UK show that the most recent decade (2008-2017) has been on average 0.3 ° C warmer than the 1981-2010 average and 0.8 ° C warmer than 1961-1990. All of the top ten warmest years have occurred since 1990. In the past few decades there has been an increase in annual average rainfall over the UK. These and future changes will impact upon viability of agriculture and aquaculture in the UK.

What evidence underpins this?

The UK Climate Projections 2018 provides a set of high-resolution spatially-coherent future climate projections. UKCP18 climate projections consist of: updated probabilistic projections, giving estimates of different future climate outcomes; a new set of global climate model projections, comprising simulations from both the latest Met Office Hadley Centre climate model and global climate models from around the world; and a set of regional climate model projections on a finer scale (12km) for the UK and Europe.

How can we practically implement this in decision support?

We can use these projections to plan land use changes and aquaculture operations in areas less impacted by extreme climate changes. The geographical location of managed realignment should take sea level rise into account, while the location of wooded areas and aquaculture will be dictated by rainfall and temperature anomalies.

UK MET Office (2018). UK Climate Projections 2018 (UKCP018). URL (accessed May 2021): https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/about

POTENTIAL FOR MARINE AQUACULTURE DEVELOPMENT IN AND AROUND MARINE PROTECTED AREAS (MPAS) IN ENGLAND

POLICY BRIEF

This briefing summarises the findings of a report submitted to Research England in September 2020.

Recommended citation
Brown AR, Daniels C, Jeffery K, Tyler CR (2020). Potential for marine aquaculture development in and around Marine Protected Areas (MPAs) in England. Policy Brief. 13pp.
https://www.exeter.ac.uk/research/saf/projects/strategypolicyregulation/

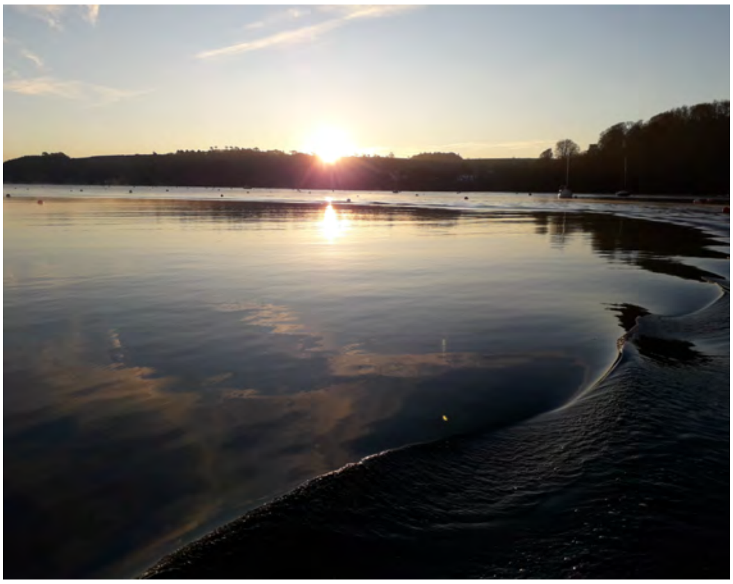
SUMMARY

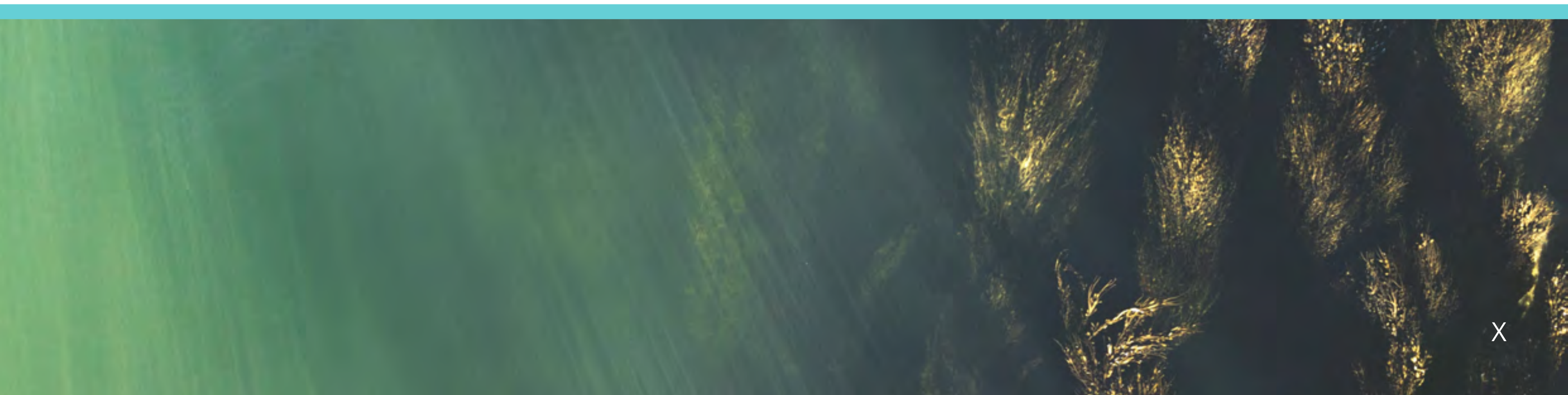
- Food fish production from aquaculture (82 million tonnes, US$250 billion per year) now exceeds that from marine capture fisheries, many of which have reached maximum sustainable yields.
- Aquaculture is the fastest growing food production sector globally (currently >5% per year), but continued rapid growth is needed to meet rising global demands for human dietary protein.
- Marine aquaculture can contribute substantially to sustainable ‘blue’ growth in the EU and the UK.
- Marine aquaculture in England (predominantly shellfish) currently occupies less than 0.5% of the country’s territorial coastal waters (12 nautical mile limit), compared with 50% occupied by Marine Protected Areas (MPAs) and with limited restriction of fishing activities (e.g. bottom trawls in MPAs).
- Around 50 (>70%) of existing marine aquaculture sites in England are located in MPAs, but licencing of new aquaculture sites within these areas currently adopts a highly precautionary approach.
- Evidence-based policy and decision support tools are urgently needed to support the sustainable management of marine resources and competing uses in England’s coastal waters.
- Allocated Zones for Aquaculture are used widely in Europe to facilitate sustainable development and a similar approach could be implemented in England by adapting existing domestic policies and tools for fisheries management and conservation.

Summary of initial findings of a report on 'Evidence-based policy for mariculture development in and around Marine Protected Areas (MPAs) in England' (Brown et al., 2020).

GLOSSARY OF TERMS

AMA - Aquaculture Management Area
AZA - Allocated Zone for Aquaculture
AZE - Allowable Zone of Effect
CEFAS - Centre for Environment Fisheries and Aquaculture Science
Feature - defined habitats composed of distinctive biological or geological sub features
HRA - Habitats Regulations Assessment
IFCA - Inshore Fisheries Conservation Authority
MEA - Marine Economic Activity
MMO - Marine Management Organisation
MPA - Marine Protected Area
NE - Natural England
VME - Vulnerable Marine Ecosystem



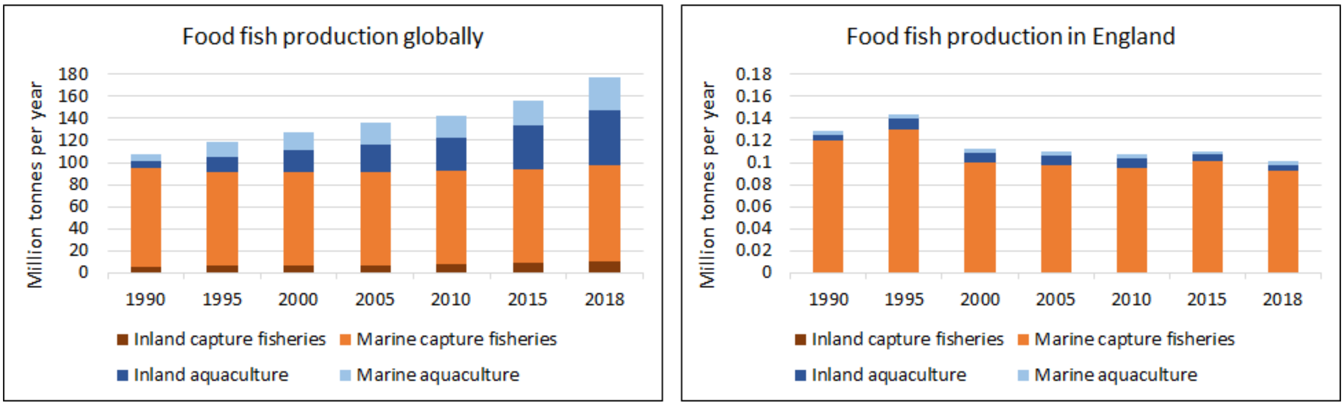


Sustainable growth and benefits of marine aquaculture including in England

Aquaculture offers considerable potential for sustainable growth in food production, unlike capture fisheries, many of which have reached maximum sustainable yields (**Figure 1**).

Figure 1: Trends in food fish production from aquaculture and capture fisheries

Aquaculture production has increased steadily on a global scale (but not in England) in the last three decades, while production from capture fisheries has plateaued. *Global data obtained from the UN Food and Agriculture Organisation; data for England obtained from CEFAS, MMO and SeaFish.*



Global food fish production from aquaculture (82 million tonnes, US$250 billion per year) now exceeds capture fisheries and production is projected to rise to 109 million tonnes, by 2030 (FAO, 2020). Especially strong growth is expected in marine aquaculture (FAO, 2020).

The UK currently generates less than 0.5% of annual global aquaculture production, mainly from Scottish sea salmon and shellfish (£900 million) (Seafish, 2016; Munro, 2019, 2020). English aquaculture currently generates only 8,000 tonnes (£30 million) of food fish per year, compared to English capture fisheries landings of 93,000 tonnes (£209 million) in 2018 (Figure 1). There is significant growth potential, particularly for marine shellfish (and seaweeds) in England, with a doubling in production projected over the next 20 years (Seafish, 2017). Greater economic growth is expected in the seafood value chain, including food processing, hospitality and tourism industries, benefiting local coastal communities in England in particular (SeaFish, 2017).

EVIDENCE

Human health benefits and significant reductions in national healthcare costs have been linked to the increased consumption of seafood, rich in proteins and micronutrients, including omega-3 fatty acids (UK Public Health Directorate, 2013; Seafish, 2017).

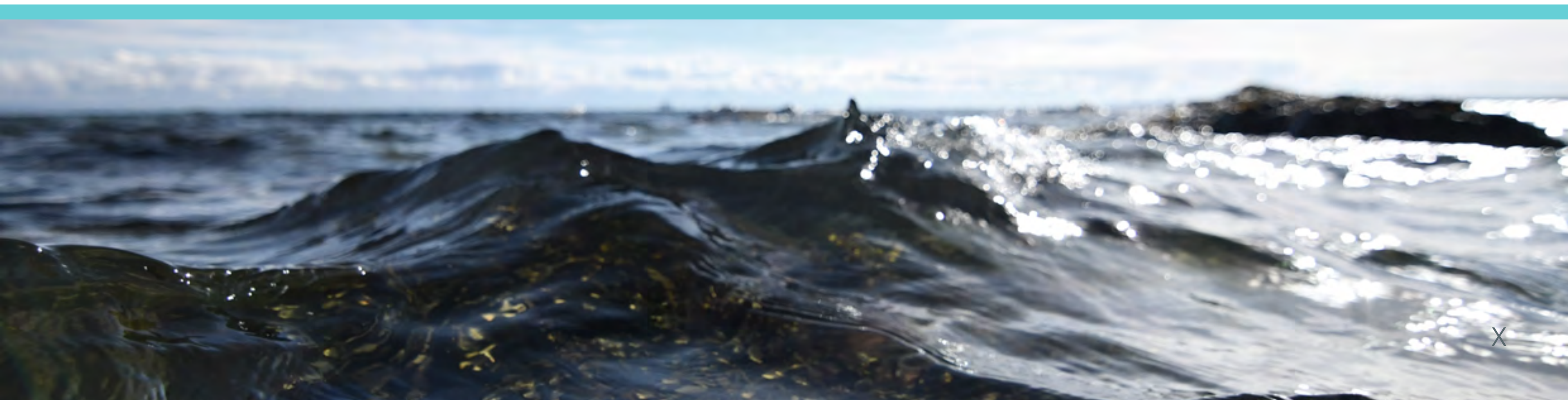
Numerous other important ecosystem services can be derived through the farming of filter feeding shellfish and seaweeds, in addition to food provisioning, including: nutrient regulation, habitat provisioning and enhancement of biodiversity and commercial fisheries (Le Gouvello et al., 2017; Smaal et al., 2018; IUCN, 2020). However, there are also potentially negative impacts of aquaculture on ecosystem services and net effects need to be better quantified, as they may vary considerably across different sites (Campbell et al., 2019; Van der Schatte et al., 2018).

> **Aquaculture can contribute to:**
>
> **Aichi Targets under the Convention on Biological Diversity**
> (6) - sustainable fisheries and
> (11) - marine biodiversity protection
>
> **UN Sustainable Development Goals:**
> (2) - food security
> (14) – oceans
>
> **(IUCN, 2020)**

Aichi Targets
Convention on Biological Diversity

SUSTAINABLE DEVELOPMENT GOALS

> **Current total landings of all wild-capture fisheries could be generated from mariculture in as little as 0.015% of the world's coastal oceans**
>
> **(Gentry et al, 2017).**



EVIDENCE

Sustainable development through marine spatial planning

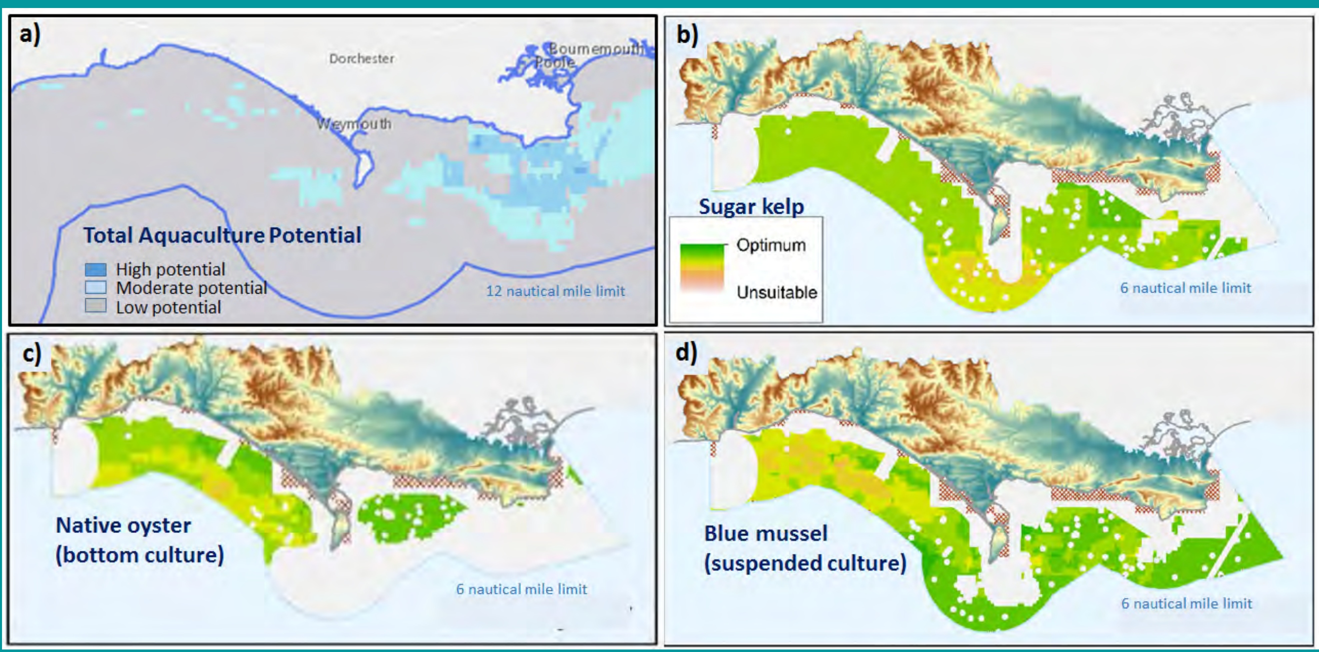
The Marine Management Organisation's (MMO's) 'Explore Marine Plans tool' is designed to identify possible sites for sustainable aquaculture development in England's coastal waters, taking into account planning constraints due to other Marine Economic Activities and Marine Protected Areas (MPAs). The tool is being further developed to include a broader range of environmental constraints, such as water quality, nutrient load and primary productivity. However, additional spatial resolution and specificity are needed for optimising the use of marine space by distinguishing areas that are suitable for different forms of aquaculture (**Case study 1, Figure 2**).

> **The UK Government's 25-year plan** aims to ensure "English inshore and offshore waters achieve good environmental status …. while allowing marine industries to thrive".
>
> **(DEFRA, 2019)**

Case study 1: Distinguishing areas that are suitable for specific forms of marine aquaculture

Figure 2: Marine aquaculture potential along the Dorset and East Devon coast

a) Total aquaculture potential according to the MMO. Specific aquaculture potential according to CEFAS (Kershaw et al., 2020) for **b)** sugar kelp (seaweed), **c)** native oyster, **d)** blue mussel



Realising opportunities for synergies between marine aquaculture development and nature conservation

Half (50%, 25,102 km2) of English inshore waters (out to the 12 nautical mile territorial limit) are designated for nature conservation within 154 MPAs, and (37%, 66,504 km2) of offshore waters contain 40 MPAs (JNCC, 2019). The majority of inshore waters are also open to fishing (MMO, 2018) and a range of other marine activities. This intense competition for marine space is recognised in the UK Multi-annual National Plan for the Development of Sustainable Aquaculture (DEFRA, 2015).

In order to resolve potential conflicts between marine activities in England's crowded coastal waters, there is a need to seek opportunities for synergies between marine uses, and to identify and understand possible trade-offs, to enable sustainable development alongside marine environmental protection and conservation.

One approach is to refine and use tools for assessing the compatibility of habitat features with different aquaculture methods, building on generic pressure-feature sensitivity assessments underpinning Natural England's advice on operations.

Another approach being adopted widely in Europe is the establishment of Allocated Zones for Aquaculture 'AZAs' (**Figure 3**), where aquaculture development can be aligned with the objectives of other marine economic activities and also MPAs (Sanchez-Jerez et al., 2016; FAO, 2019). Marine policy making and decision support tools required for establishment of AZAs in England could be drawn from existing policy frameworks for fisheries management and conservation (DEFRA, 2012), fisheries byelaws, Regulating Orders and Several Orders (Seafish, 2016). (**Case study 2, Figure 4**)

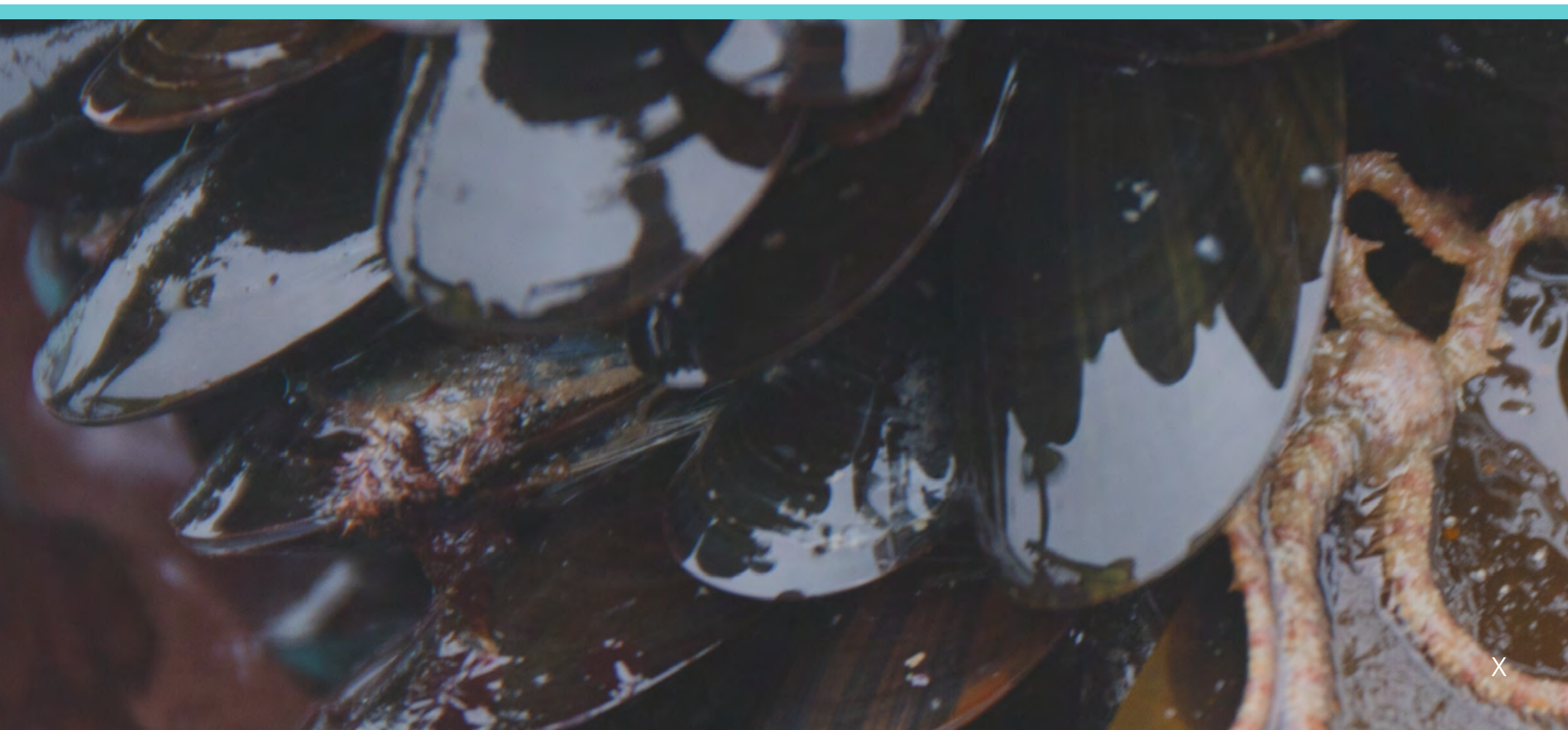
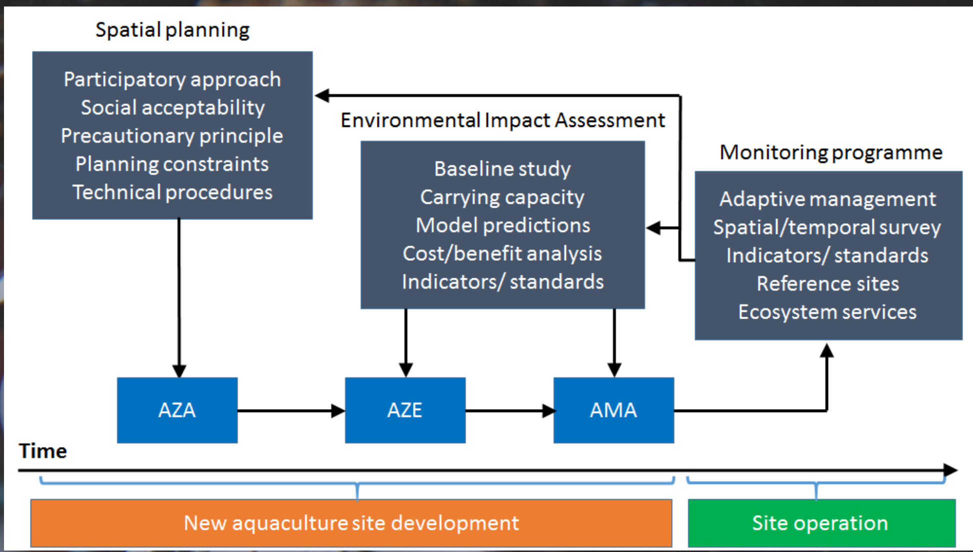


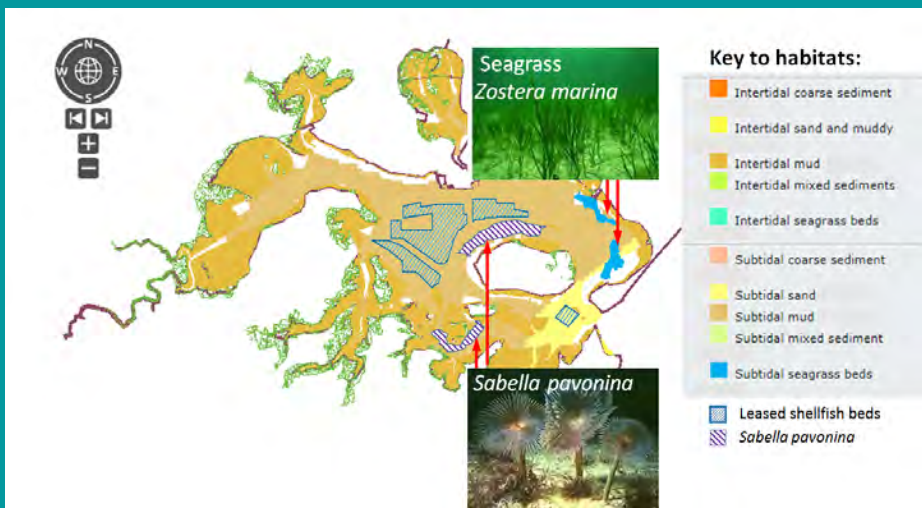
Figure 3: Ecosystem approach for sustainable development of marine aquaculture within AZAs

The ecosystem approach outlined below includes the definition of an Allocated Zone for Aquaculture (AZA), definition of an Allowable Zone of Effect (AZE) and an Aquaculture Management Area (AMA) (after Sanchez-Jerez et al., 2016).



Case study 2: Long-standing example of an Allocated Zone for Aquaculture (AZA) in Poole Harbour

Figure 4: Mapping of leased shellfish beds, habitat features, sub features

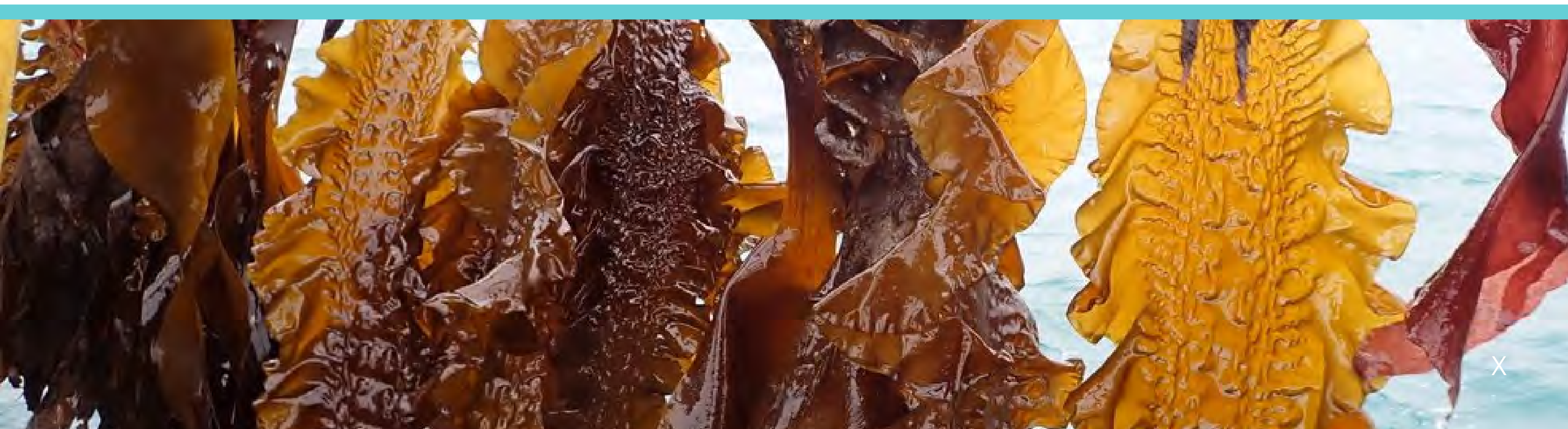


Poole Harbour is one of the largest coastal lagoons in Europe. It is an MPA (Special Protection Area and Ramsar site), which has supported a thriving shellfish aquaculture industry, managed via a Several Order since 1915 (Southern IFCA, 2020). Currently 24% of the Poole Harbour MPA is leased for bottom-culture of shellfish (blue mussels, Pacific oysters, edible cockles and Manilla clams). The leased area constitutes an AZA, located on sub-tidal mud, away from sensitive species and habitats, including seagrass beds (Zostera marina), peacock worms (Sabella pavonina) and internationally important populations of intertidal wading birds.

DISCUSSION

Alternative frameworks
for assessing the compatibility of different types of marine aquaculture in and around MPAs

Precautionary, feature-based approach
Marine aquaculture developments require screening to (determine the need for Environmental Impact Assessment) and Habitats Regulations Assessment (HRA, for European Marine Sites) to evidence that designated habitat features are maintained in a favourable condition. There are several short comings in this 'feature-based approach', including: (i) Lack of representation of species and habitats within the UK's MPA network, which are not included among designated habitat features; (ii) Practical limitations for accurately mapping the distribution and extent of many features; (iii) Lack of reliable indicators to assess changes in feature condition; (iv) Infrequent monitoring of feature condition e.g. every six years for Marine Conservation Zones (Ware and Downie, 2020). These practical (and economic) constraints lead to a reliance on wider published evidence of feature sensitivity to specific pressures from marine activities (Tyler-Walters, 2018). However, sensitivity assessments fail to account explicitly for duration or extent of pressures (CEFAS, 2012) and there are limited data for benchmarking specific pressures from marine aquaculture (Brown et al., 2020), including discerning when aspecific pressure leads to an adverse impact on a feature, and distinguishing this from other anthropogenic or natural background pressures (Möckel, 2017). Lack of site- and feature- specific evidence leads to application of the precautionary principle. For example, there is a tendency under the UK Habitats Regulations to afford the highest levels of conservation protection to all 'natural habitats' and 'habitats of species', at the expense of sustainable development (Solandt et al., 2020). For example, some habitats, such as reefs are recognised as being particularly vulnerable to towed fishing gear and marine plans generally consider reefs to be vulnerable marine ecosystems (VMEs). However, there is evidence that static fishing gears, which more closely resemble marine aquaculture activities, have limited impact on reefs (Rees et al., 2019). Furthermore, the feature-based approach to MPA management places little, or no, emphasis on assessing net impacts, including the positive impacts of marine aquaculture on biodiversity conservation within MPAs, or on other ecosystem services and dependent marine economic activities, including fishing.



DISCUSSION

Participatory, ecosystem-based approach

An alternative approach to the feature-based approach is to protect whole ecosystems, which is advocated in UK Government's 25 year Environmental Plan (DEFRA, 2019). This 'whole site', 'ecosystem-based approach' seeks to preserve structure and function, and enable the repair and renewal of marine systems, and is more consistent with the sustainable development and use of marine resources (Solandt et al., 2020; Rees et al., 2020). This approach is embodied in DEFRA's 'revised approach' to the management of commercial fisheries in European Marine Sites in England (DEFRA, 2012) and JNCC's participatory approach to fisheries management in MPAs (JNCC, 2020). In addition to protecting the most vulnerable habitat features within a site from higher risk fishing activities (e.g. demersal trawling), adaptive risk management (based on ongoing monitoring and assessment) can be used to regulate fishing in habitat areas where evidence of negative impacts is lacking.

Adaptive risk management

Adaptive risk management takes into account: conservation feature condition and extent; sensitivity to the specified activity; spatial distribution and intensity of the activity; evidence on other background pressures; trends indicating whether features are progressing towards achieving their conservation objectives. This approach is integral to marine aquaculture management in AZAs (**Figure 3)** (Sanchez-Jerez et al., 2016; FAO, 2019).

Environmental monitoring is required to ensure the adaptive management and sustainable development of marine aquaculture, including within MPAs. Current levels/frequencies of habitat feature condition monitoring undertaken by JNCC and Natural England are limited. Additional regulatory-approved, industry-sponsored monitoring would support both marine aquaculture and MPA management.

RECOMMENDATIONS

Establishing Allocated Zones for Aquaculture (AZAs) in England's crowded coastal waters, including within **Marine Protected Areas (MPAs)** requires the refinement and use of a suite of tools. These tools include:

1) Habitat feature-based sensitivity matrices for prospective assessment of the suitability of different types of marine aquaculture:

- o Feature-specific risk assessment should be refined, building on Natural England's (generic) risk matrices and environmental monitoring data from existing sites quantifying aquaculture x MPA feature interactions.
- o General rules for the screening of proposed marine aquaculture developments should be established, based on learning gained from risk matrices and environmental monitoring data.

2) Adaptive risk management of ongoing aquaculture developments (pilot studies) and operations:

- o Marine aquaculture developments and site operations in and around MPAs should be informed by evidence gathered from ongoing monitoring of habitat features in relation to planned and implemented aquaculture activities.
- o Comparing evidence from monitoring of aquaculture sites and reference sites (e.g. HRA sites) will help elucidate trends in feature condition and impacts from other (background) pressures.

3) Tools quantifying ecosystem service benefits provided by different forms of marine aquaculture, including habitat provisioning, coastal protection, nutrient regulation, carbon sequestration.

4) General planning rules developed from the above tools – these should be applied within a transparent decision making framework for regulators and prospective marine aquaculture licensees (see Daniels et al., 2020; SeaFish, 2020).

AUTHORS

Dr Ross Brown is a Senior Research Fellow with 25 years of experience in industry, in environmental risk and impact assessment. He has more recently (over the last 6 years) developed a portfolio of projects in Sustainable Aquaculture Futures at the University of Exeter.

Dr Carly Daniels is a Research Fellow at the University of Exeter, with 15 years in marine conservation and aquaculture, working at the interface between industry and science. Carly has developed and managed projects in fisheries stock enhancement, mariculture and environmental monitoring.

Keith Jeffery is Group Manager of Statutory Aquatic Services within the Centre for Environment Fisheries and Aquaculture Science. He was previously responsible for statutory inspections of aquaculture production businesses with the Fish Health Inspectorate.

Professor Charles Tyler is an Environmental biologist in the College of Life and Environmental Sciences at the University of Exeter. He leads various (inter)national strategic research partnerships including with CEFAS. He is Co-Director of the centre for Sustainable Aquaculture Futures, GW4 Water Security Alliance, Aquaculture Research Hub UK.

ACKNOWLEDGEMENTS

The authors are very grateful to: **Roger Covey (Natural England)** and **Pia Bateman (Southern Inshore Fisheries Conservation Authority)** for their expert opinion and guidance, and for providing links to a range of conservation planning resources for MPAs and mariculture, which are referenced in this document.

Author affiliations:

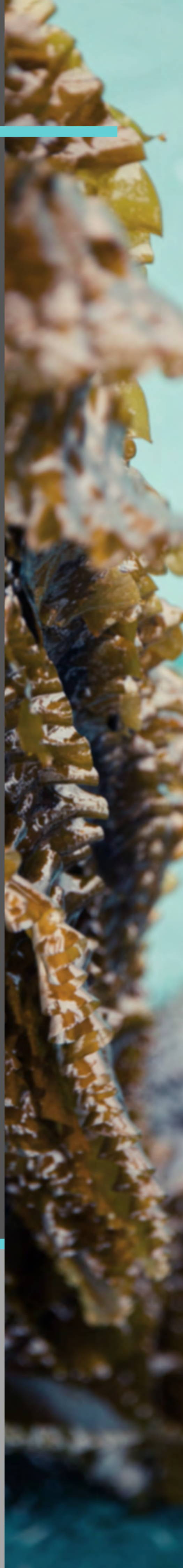
University of Exeter
Cefas
sweep
SAF

Work funded by:

UKRI Research England
UKRI Natural Environment Research Council

Published by:

Mindfully Wired Communications



REFERENCES

Brown et al. (2019). Assessing risks and mitigating impacts of harmful algal blooms on mariculture and marine fisheries. Reviews in Aquaculture 12(3):1663-1688.

Brown et al. (2020). Developing general rules to facilitate evidence-based policy for mariculture development in and around Marine Protected Areas (MPAs) in England. Report to Research England (Strategic Priorities Fund), 30pp. https://www.exeter.ac.uk/research/saf/projects/strategypolicyregulation/

Campbell et al. (2019) The environmental risks associated with the development of seaweed farming in Europe - Prioritizing key knowledge gaps. Frontiers in Marine Science 6:107.

CEFAS (2012). Fisheries in European Marine Sites: review of the matrix'. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/310814/cefas_matrix_review.pdf

CEFAS (2020). Aquaculture Mapping Project – Dorset and East Devon FLAG Area. Mapping areas of potential aquaculture within the Dorset and East Devon FLAG Area. Report C7731.

Daniels et al. (2020) Supporting Mariculture Development: Evidence for Informed Regulation. Policy Brief. 21pp. https://www.exeter.ac.uk/research/saf/projects/strategypolicyregulation/

DEFRA (2012). Revised approach to the management of commercial fisheries in European marine sites in England: https://www.gov.uk/government/publications/revised-approach-to-the-management-of-commercial-fisheries-in-european-marine-sites-overarching-policy-and-delivery

DEFRA (2015). United Kingdom multiannual national plan for the development of sustainable aquaculture.https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/480928/sustainable-aquaculture-manp-uk-2015.pdf

DEFRA (2019). HM Government: A Green Future: Our 25 Year Plan to Improve the Environment https://www.gov.uk/government/publications/25-year-environment-plan

FAO, Food and Agriculture Organisation (2019). Allocated Zones for Aquaculture: A guide for the establishment of coastal zones dedicated to aquaculture in the Mediterranean and the Black Sea. http://www.fao.org/3/ca7041en/CA7041EN.pdf

FAO, Food and Agriculture Organisation (2020). The State of the World Fisheries and Aquaculture 2012. http://www.fao.org/3/ca9229en/ca9229en.pdf

Gentry et al. (2017) Mapping the global potential for marine aquaculture. Nature Ecology and IUCN, International Union for the Conservation of Nature (2020). Aquaculture and Marine Protected Areas: Exploring Potential Opportunities and Synergies. URL (2020): https://www.iucn.org/sites/dev/files/content/documents/aquaculture_and_marine_protected_areas.pdf

Huntington and Cappell (2020). English Aquaculture Strategy. Draft. Produced by Poseidon Aquatic Resources Management Ltd.

JNCC, Joint Nature Conservation Committee (2019). UK Marine Protected Area network statistics. https://jncc.gov.uk/our-work/uk-marine-protected-area-network-statistics/

JNCC, Joint Nature Conservation Committee (2020). MPA Fisheries Management Toolkit. http://data.jncc.gov.uk/data/da4ae34c-d0f3-41df-b4fd-79df0a079647/MPA-Fisheries-Management-Toolkit-FINAL.pdf

Kershaw et al. (2020). Mapping of Areas of Potential Aquaculture within the Dorset and East Devon Fisheries Local Action Group (FLAG) area. Cefas Contract C7731, European Maritime and Fisheries Fund (EMFF) grant number ENG3016, pp. 1-187.

Le Gouvello et al. (2017). Aquaculture and marine protected areas: Potential opportunities and synergies. Aquatic Conservation: Mar Freshw Ecosyst. 27(S1):138–150.

MMO, Marine Management Organisation (2018). UK Sea Fisheries Statistics 2017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/742793/UK_Sea_Fisheries_Statistics_2017.pdf

REFERENCES

MMO, Marine Management Organisation (2019). Identification of Areas of Aquaculture Potential in English Waters, A report produced for the Marine Management Organisation by Centre for Environment Fisheries and Aquaculture Science, MMO Project No: 1184, May 2019, 107 pp.

Möckel (2017). The assessment of significant effects on the integrity of "Natura 2000" sites under Article 6(2) and 6(3) of the Habitats Directive. Nature Conservation 23: 57-85.

Munro LA (2019). Marine Scotland Science: Scottish fish farm production survey 2018. 48 pp. https://www.gov.scot/publications/scottish-fish-farm-production-survey-2018/

Munro LA (2020). Marine Scotland Science: Scottish Shellfish Farm Production Survey 2019. 26 pp. https://www.gov.scot/publications/scottish-shellfish-farm-production-survey-2019/

Rees et al. (2018). The Lyme Bay experimental potting study: A collaborative programme to assess the ecological effects of increasing potting density in the Lyme Bay Marine Protected Area. A report to the Blue Marine Foundation and Defra, by the Marine Institute at the University of Plymouth.

Rees et al. (2020). Emerging themes to support ambitious UK marine biodiversity conservation. Marine Policy 117, 103864.

Sanchez-Jerez et al. (2016). Aquacultures struggle for space: The need for coastal spatial planning and the potential benefits of allocated zones for aquaculture (AZAs) to avoid conflict and promote sustainability. Aquaculture Environment Interactions, 8: 41–54.

SeaFish (2016). SR695 UK Shellfish Production and Several, Regulating and Hybrid Orders: The Contribution and Value of Orders in Relation to the Sector's Past Development and Future Growth. https://www.seafish.org/media/publications/FINAL_SRO_REPORT_-_AUGUST_2016_FINAL.pdf

SeaFish (2017). Sea Food 2040 – A strategic framework for England. https://seafish.org/media/Seafood%202040%20strategic%20framework.pdf

Smaal AC, Ferreira JG, Grant J, Petersen JK, Strand Ø (Ed.s) (2018). Goods and services of marine bivalves. Springer. https://doi.org/10.1007/978-3-319-96776-9.

Solandt et al. (2020). Managing marine protected areas in Europe: Moving from 'feature-based' to 'whole-site' management of sites. In Eds Humphreys J and Clarke RWE, Marine Protected Areas - Science, Policy and Management 2020, Pages 157-181, Publ. Elsevier, London.

Southern IFCA, Inshore Fisheries Conservation Authority (2020). Southern Inshore Fisheries and Conservation Authority Poole Harbour Several Order 2015 Management Plan (2020 revision).

Tyler-Walters et al. (2018). Marine Evidence-based Sensitivity Assessment (MarESA) – A Guide. Marine Life Information Network (MarLIN). Marine Biological Association of the UK, Plymouth, pp. 91. https://www.marlin.ac.uk/publications

UK Public Health Directorate (2013). Nutrient analysis of fish and fish products, summary report. Prepared by the Food Composition and Diet Team, Public Health Directorate. URL https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/167921/Nutrient_analysis_of_fish_and_fish_products_-_Summary_Report.pdf

Van der Schatte et al. (2018). A global review of the ecosystem services provided by bivalve aquaculture. Reviews in Aquaculture, 1–23 DOI: 10.1111/raq.12301.

Visch et al. (2020). Environmental impact of kelp (Saccharina latissima) aquaculture. Marine Pollution Bulletin 155, 110962.

Ware and Downie (2020). Challenges of habitat mapping to inform marine protected area (MPA) designation and monitoring: An operational perspective. Marine Policy 111: 103717. https://doi.org/10.1016/j.marpol.2019.103717

Developing general rules to facilitate evidence-based policy for mariculture development in and around Marine Protected Areas (MPAs) in England

Final Report to Research England (Strategic Priorities Fund)

September 2020

Authors:

A Ross Brown[1], Carly Daniels[1], Keith Jeffery[2], Charles R Tyler[1].

Affiliations:

1) Sustainable Aquaculture Futures, Biosciences, Geoffrey Pope Building, Stocker Road, Exeter, EX4 4QD.

2) Centre for Environment Fisheries and Aquaculture Science, The Nothe, Barrack Road, Weymouth, Dorset DT4 8UB.

Suggested citation:

Brown AR, Daniels C, Jeffery K, Tyler CR (2020). Developing general rules to facilitate evidence-based policy for mariculture development in and around Marine Protected Areas (MPAs) in England. Report to Research England (Strategic Priorities Fund), 30pp. https://www.exeter.ac.uk/research/saf/projects/strategypolicyregulation/

CONTENTS

1) EXECUTIVE SUMMARY

- Marine ecosystems face ever-increasing demands from human activities and there is an urgent need for evidence-based policy and decision making to ensure sustainable management of marine resources.
- Globally, marine capture fisheries have plateaued or are in decline, driving the need for aquaculture expansion to satisfy an ever increasing demand for seafood.
- Marine aquaculture (mariculture) has considerable potential to contribute to sustainable 'blue' growth in the UK, particularly in England where the industry (predominantly shellfish mariculture) currently occupies a very small proportion (<0.1%) of the country's territorial coastal waters.
- The majority (>70%) of mariculture sites in England are located within MPAs and have co-existed as such over long periods of time (for up to 100 yrs).
- We evaluate the availability of baseline data, and the development of habitat feature-specific risk assessment tools and general rules for facilitating mariculture development within MPAs.
- In the final analysis, we set out a series of recommendations for the development of MPA/marine planning assessment tools and rules and their integration within a transparent decision making framework (e.g. decision tree) for regulators and prospective mariculture licencees.

2) OVERARCHING AIM

This project set out to provide a synthesis of evidence and recent developments in marine policy making and decision support tools for enabling the sustainable development of mariculture sites, species and technologies in and around marine protected areas (MPAs).

3) BACKGROUND

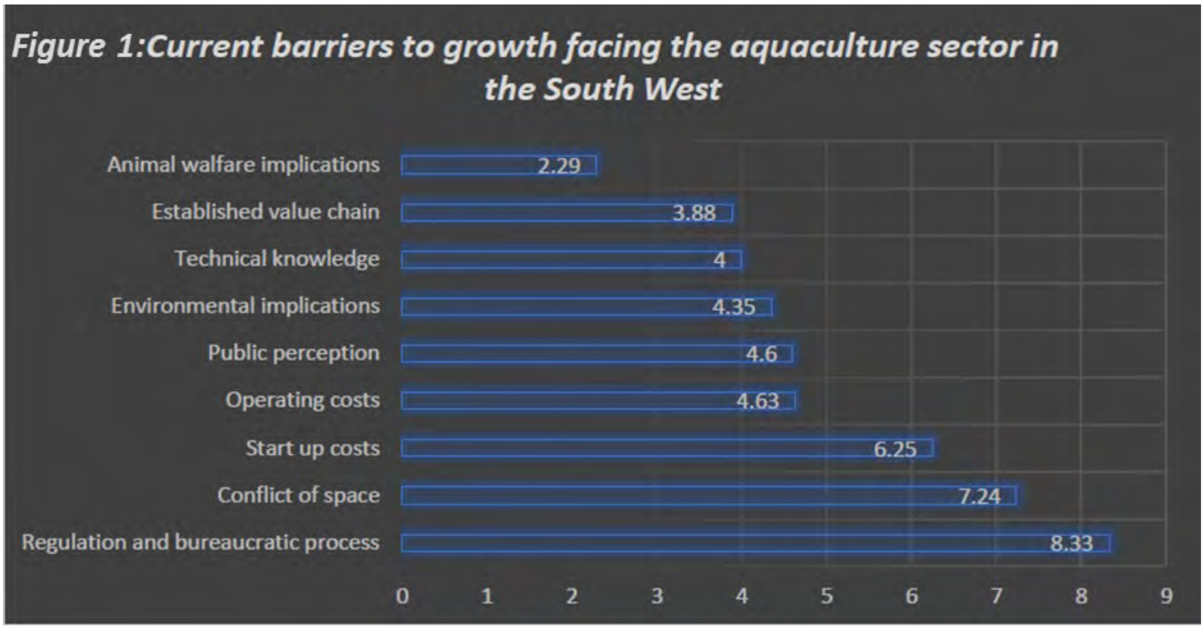
3.1) The potential for growth in aquaculture, particularly marine aquaculture in England

Aquaculture is the fastest growing food production sector globally (FAO, 2020) and unlike agriculture and capture fisheries, which are plateauing or declining (Asche and Smith, 2018; FAO, 2020), offers huge potential for future sustainable growth (DEFRA, 2015; Westbrook, 2017; Seafish, 2017). Global food fish production from aquaculture (82 million tonnes, US$250 billion per year) now exceeds capture fisheries and production is projected to rise to 109 million tonnes, by 2030 (FAO, 2020), with a significant contribution coming from marine aquaculture (mariculture) (Kapetsky et al., 2013; EEA, 2017; FAO, 2020). The UK mariculture industry generates <1% of annual global aquaculture product sales (£1.8 billion) from ~0.2 million tonnes of farmed seafood, which is dominated by Scottish salmon and shellfish (Seafish, 2016). There is significant potential to grow the UK mariculture industry (Seafish, 2016; UK Government Office for Science, 2017), particularly in England where turnover is projected to rise from 2% to 4% (£30 million to £60 million) of UK sales over the next 20 years (Seafish, 2017). A major factor contributing to the growth potential for mariculture in England is its long coastline, which is the third longest of all EU countries (UK Government Office for Science, 2017). However this coastline currently supports 20 times lower production (per km) compared to Northern France (EEA, 2017). More extensive growth in revenues and jobs are likely to be generated in coastal communities in England by an enhanced seafood value chain, including food processing, restaurant, hospitality and tourism industries (SeaFish, 2017). The increased production and consumption of seafood, rich in proteins, micronutrients and omega 3 fatty acids, is expected to bring considerable human health benefits and significant reductions in national healthcare costs (Seafish, 2017). There are also numerous ecosystem service benefits associated with some mariculture practices, in particular from shellfish and seaweed mariculture, including habitat provisioning and enhancement of biodiversity and commercial fisheries (Le Gouvello et al., 2017).

3.2) Key factors constraining mariculture expansion

A broad range of factors potentially constrain mariculture expansion. Key socio-economic factors include burdensome and bureaucratic regulation (DEFRA, 2015), competition/conflict with other marine sectors for marine space (Kapetsky et al., 2013, Gentry et al., 2017), financial and technical demands associated with licencing and operation, public perception of aquaculture and dietary preferences for, finfish and crustaceans with wild provenance (Villasante et al., 2013; Gentry et al., 2017). Key environmental factors include variable water quality (Muir, 1992), climate change, ocean acidification (Clements and Chopin, 2017), and harmful algal blooms (Brown et al., 2019).

Barriers faced by the aquaculture sector in SW England have been ranked in their importance by 22 industry, academic and regulator stakeholders in the South West Aquaculture Network (**Figure 1**).



Values on bar chart represent the average importance score – averaged across 22 survey participants (importance was scored by all participants from 1 to 9, least to most important barrier).

4) METHODS

In order to help overcome the key constraint of conflict for marine space we examined scientific evidence and recent developments in marine policy making and decision support tools concerning the co-location of aquaculture sites, farmed species and technologies in and around MPAs. We then used this evidence to generate a set of policy recommendations for facilitating sustainable development of mariculture in and around MPAs. The work was undertaken in four stages:

4.1) Initial consultation and scoping (Stage 1)

Relevant competent authorities comprising the Centre for Environment Fisheries and Aquaculture Science (CEFAS), Natural England (NE) and the Inshore Fisheries Conservation Authority (IFCA) were consulted at the outset of the project in order identify key information sources and data gaps concerning interactions between mariculture and MPAs.

4.2) Literature review (Stage 2)

A literature review was undertaken to appraise data and tools highlighted in Stage 1 (Section 4.1) and to develop a narrative concerning trends in policy development on the sustainable use of marine resources alongside nature conservation. The review considered international policy and regulatory instruments, but focused primarily on national policy and regulation relating to the management of MPAs alongside mariculture operations and also capture fisheries.

4.3) Case study (Stage 3)

A case study was undertaken in SW England, along the Dorset and East Devon coast, in order to develop general rules (supported by an evidence base derived from the scientific literature, policy reviews and stakeholder consultation) for mariculture development around MPAs. In particular this study evaluated the feasibility of using available evidence and tools (identified in Stage 1) for assessing mariculture-MPA interactions and for screening the compatibility of mariculture species and technologies with specific conservation features (i.e. sedimentary or reef habitat features listed in Annex 1 of the Habitats Directive).

4.4) Multi-stakeholder workshop (Stage 4)

The work presented in this report was summarised and presented to 40 regulatory, industry and academic stakeholders at a virtual workshop on '*Supporting Mariculture Development - Evidence for Informed Regulation*', which addressed the key constraint of Regulation and bureaucratic process (**Figure 1**). During and after the workshop stakeholders were asked to prioritise and feedback on a range of issues, including perceived positive and negative impacts of mariculture on MPAs. The workshop was conducted and is reported separately under a parallel and complimentary SPF project (Daniels et al., 2020).

5) RESULTS

5.1) Initial consultation and scoping

Consultation with CEFAS, Natural England and IFCA took place on 20 February 2020 and minutes are recorded in **Appendix 1**. The consultation identified a number of key resources that provided a starting point for the literature review (Stage 2) and the case study (Stage 3). These resources included: i) Natural England's 'advice on operations' in MPAs concerning mariculture species (finfish, shellfish, seaweed) and specific culture technologies (bottom culture, trestle culture, rope culture) https://www.gov.uk/government/collections/conservation-advice-packages-for-marine-protected-areas; ii) Natural England's and IFCA's geospatial maps of MPAs (and habitats and specific conservation features) https://magic.defra.gov.uk/ and iii) CEFAS's detailed geospatial assessment of the feasibility of aquaculture operations (based on environmental conditions and competing uses) along the Dorset and East Devon coastline out to 6 nautical miles http://data.cefas.co.uk/. Additional resources for informing 'general rules' for mariculture development in and around Marine Protected Areas (MPAs) that were identified (and evaluated in the literature review - Stage 2) included: the Marine

Management Organisation's Matrix of fisheries gear types and European Marine Site protected features https://www.gov.uk/government/publications/fisheries-in-european-marine-sites-matrix and Habitat Risk Assessments and Zoning under the Williamsburg Resolution relating to aquaculture and fish movements. http://www.nasco.int/pdf/far_aquaculture/AquacultureFAR_EnglandWales.pdf

5.2) Literature review

5.2.1) Reconciling nature conservation and sustainable development of mariculture

The UK Government's 25-year plan (DEFRA, 2019) states that "English inshore and offshore waters and Northern Ireland offshore waters will achieve good environmental status (Marine Strategy Framework Directive MSFD 2008/56/EC)…. while allowing marine industries to thrive….", which will be achieved in part by establishing an "ecologically coherent network of well-managed marine protected areas (MPAs)". The plan also highlights Defra's ambition for more collaborative management by "joining forces with local stakeholders to find the most appropriate ways of drawing down the riches of the sea in a sustainable way". The International Union for the Conservation of Nature (IUCN) also highlights potential opportunities & synergies between aquaculture (mariculture) and nature conservation in relation to meeting Aichi Targets by 2020: Target 11 - marine biodiversity protection; Target 6 - sustainable fisheries (CBD, 2010), and achieving UN Sustainable Development Goals (2030): Goal 2 - food security; Goal 14 – oceans (IUCN, 2020).

Despite international acknowledgement for the need to reconcile nature conservation and sustainable development (IUCN, 2020), nature conservation in England, the UK and EU follows a 'precautionary approach'. Environmental Impact Assessment (EIA) screening is mandatory for shellfish and finfish mariculture developments, including in sensitive areas such as MPAs.

In the case of European Marine Sites designated under the Habitats Directive (92/43/EEC) and/or Birds Directive (79/409/EEC) an assessment is also required to demonstrate that the integrity of the sites will not be adversely impacted (EC, 2012; Möckel, 2017). In the UK, this assessment is a Habitats Regulations Assessment (HRA), performed under the Conservation (Natural Habitats &c.) Regulations (2019) by competent authorities (the authorising or consenting body) advised by Natural England. Assessments must show that designated habitat features within protected sites are maintained in favourable condition (i.e. feature extent is stable or increasing, structures and functions necessary for maintenance are likely to exist for the foreseeable future, populations of typical species associated with the habitat are viable in long-term). Despite distinctions being made for priority habitats and features, which are particularly rare or vulnerable (nationally or internationally), or which, once destroyed, cannot be replaced there is a tendency to apply the same levels of protection to all. For example, Article 6(2) and Article 6(3) of the Habitats Directive offer the same level of protection for all 'natural habitats' and 'habitats of species'.

The effectiveness of 'feature-based approaches' for conserving marine biodiversity has been called into question, due to lack of representation of species and habitats within the MPA network, lack of reliable indicators to assess change in feature condition, inability to accurately map the distribution and extent of many features (Ware and Downie, 2020). Of further concern is the tendency for universal application of the precautionary principle to afford the highest levels of conservation protection, at the expense of sustainable development (Solandt et al., 2020). An alternative approach advocated in UK Government's 25 year Environmental Plan is to protect whole ecosystems, 'which are more than the sum of their parts, due to dynamic interaction of components through time' (DEFRA, 2018a). This 'whole site', 'ecosystem-based approach' seeks to preserve structure and function, and enable the repair and renewal of marine systems, and is more consistent with the sustainable development and use of marine resources (Solandt et al., 2020; Rees et al., 2020). Regardless of the approach taken towards sustainable development, clearer specification of significant adverse effects on MPA features is required, as well as more accurate quantification of the contribution of proposed developments towards any (cumulative) adverse effects (Möckel, 2017).

5.2.2) Availability of marine space for mariculture development

Around half ~50% (25,102 km^2) of English inshore waters (out to the 12 nautical mile territorial limit) is occupied by 154 MPAs, while 37% (66,504 km2) of offshore waters contain 40 MPAs (JNCC, 2019). The majority of inshore waters are also open to fishing (MMO, 2018) and a range of other marine activities. Furthermore, not all remaining available marine space will be suitable for mariculture development due to other constraints (including water quality, depth, exposure to wind and waves) and socio-economic factors (including proximity to ports and supply chains) (Ross et al. 2013). This highlights the need for multiple stakeholder engagement and multi-criteria decision analysis in marine spatial planning (Ross et al., 2013; Sanchez-Jerez et al. 2016) including around MPAs (Rodmell et al., 2020).

In line with the UK multi-annual national plan for the development of sustainable aquaculture (DEFRA, 2015), marine plans in England identify areas for potential aquaculture development, but there is no accompanying scheme or dispensation for facilitating licencing (SPF workshop, 2020). One solution is the establishment of allocated zones for aquaculture 'AZA' (Sanchez-Jerez et al., 2016), where aquaculture development could be directly aligned with MPA or other marine use objectives.

It is important to note that the establishment of many existing mariculture sites within MPAs predates the designation of many of these conservation sites, including European Marine Sites (EMSs) and Marine Conservation Zones (MCZs), which have proliferated following the Earth Summit in Rio de Janeiro, 1992 and the World Summit on Sustainable Development in Johannesburg, 2002 (FAO, 2009; Humphreys and Clark, 2020).

5.2.3) Development of compatibility matrices for marine activities (including mariculture) and MPAs

Compatibility matrices for different marine activities and different MPA categories (from category Ia Strict nature reserves and, Ib Wilderness areas to category VI Managed resource protected areas) were proposed provisionally by the IUCN (Day et al., 2012). The compatibility of different types of aquaculture has also been rated (yes, possible, no) for IUCN broad MPA categories (Le Gouvello et al., 2017; IUCN, 2020) (**Table 1**). Comparable rating of aquaculture, fishing and dredging in Table 1 seems unrealistic. More detailed assessments of the sensitivity of specific habitat features in English MPAs (e.g. Poole Harbour EMS) to pressures from these activities (e.g. abrasion/disturbance of the seabed, changes in suspended solids, nutrient enrichment) indicates that features are generally more sensitive to dredging than fishing or aquaculture (**Table 2**). This is according Natural England's Advice on Operations https://www.gov.uk/government/collections/conservation-advice-packages-for-marine-protected-areas, based on Marine Evidence based Sensitivity Assessment (MarESA) (Tillin et al., 2010; Tillin and Tyler-Walters, 2014), for a range of marine activities. A similar approach has been developed in Wales (Hall et al., 2008) and in Scotland http://www.sarf.org.uk/cms-assets/documents/167420-751752.sarf090.pdf. These evidence-based sensitivity assessments have been benchmarked in terms of magnitude, extent, duration and frequency of the effect, so that pressures from different activities can be compared on an equal footing https://www.marlin.ac.uk/sensitivity/sensitivity_rationale.

Sensitivity assessments are underpinned by limited data for mariculture sites and operations. Furthermore, while feature-based sensitivity assessments can be used as preliminary compatibility screening tools for mariculture and MPAs, they may be under- or over- protective. The appraisal of sensitivity matrices for MPAs relating to different fishing gear types has also highlighted that generic matrices are no substitute for site-specific vulnerability assessments, which explicitly consider the exposure of resident biological communities within habitat features to local environmental pressures (CEFAS, 2012). Feature-based tools are also no substitute for ecosystem-based methods for assessing whole site integrity (Rees et al., 2020; Ware and Downie, 2020).

Table 1: Compatibility matrices for different categories of protected areas and activities including aquaculture (IUCN, 2020).

Protected Area Category and International Name	Management Objectives
Ia – Strict Nature Reserve	Managed mainly for science
Ib – Wilderness Area	Managed mainly to protect wilderness qualities
II – National Park	Managed mainly for ecosystem protection and recreation
III – Natural Monument	Managed mainly for conservation of specific natural/cultural features
IV – Habitat/ Species Management Area	Managed mainly for conservation through management intervention
V – Protected Landscape/Seascape	Managed mainly for landscape/seascape conservation and recreation
VI – Managed Resource Protected Area	Managed mainly the sustainable use of natural ecosystem

Matrix of activities that may be appropriate for each IUCN management category.

Activities	Ia	Ib	II	III	IV	V	VI
Research: non-extractive	Y*	Y	Y	Y	Y	Y	Y
Non-extractive traditional use	Y*	Y	Y	Y	Y	Y	Y
Restoration/enhancement for conservation (e.g. invasive species control, coral reintroduction)	Y*	*	Y	Y	Y	Y	Y
Traditional fishing/collection in accordance with cultural tradition and use	N	Y*	Y	Y	Y	Y	Y
Non-extractive recreation (e.g. diving)	N	*	Y	Y	Y	Y	Y
Large scale high intensity tourism	N	N	Y	Y	Y	Y	Y
Shipping (except as may be unavoidable under international maritime law)	N	N	Y*	Y*	Y	Y	Y
Problem wildlife management (e.g. shark control programmes)	N	N	Y*	Y*	Y*	Y	Y
Research: extractive	N*	N*	N*	N*	Y	Y	Y
Renewable energy generation	N	N	N	N	Y	Y	Y
Restoration/enhancement for other reasons (e.g. beach replenishment, fish aggregation, artificial reefs)	N	N	N*	N*	Y	Y	Y
Fishing/collection: recreational	N	N	N	N	*	Y	Y
Fishing/collection: long term and sustainable local fishing practices	N	N	N	N	*	Y	Y
Aquaculture	N	N	N	N	*	Y	Y
Works (e.g. harbours, ports, dredging)	N	N	N	N	*	Y	Y
Untreated waste discharge	N	N	N	N	N	Y	Y
Mining (seafloor as well as sub-seafloor)	N	N	N	N	N	Y*	Y*
Habitation	N	N*	N*	N*	N*	Y	N*

Categories	Ia	Ib	II	III	IV	V	VI
High density fish cage culture	N	N	N	N	*	*	*
High density on-land close system fish culture	N	N	N	N	*	*	Y
Medium density on-land circulating system fish pond culture	N	N	N	N	*	Y	Y
High density shell fish culture (table, long-lines)	N	N	N	N	*	*	Y
Low density pond /lagoon fish culture	N	N	N	N	*	Y	Y
High density seaweed culture	N	N	N	N	*	*	Y
Low density shellfish culture	N	N	N	N	*	Y	Y
Medium density invertebrate (e.g. sea cucumber) culture	N	N	N	N	*	Y	Y
Integrated Multi-trophic culture	N	N	N	N	*	Y	Y
Restoration purpose aquaculture *	*	*	*	*	*	Y	Y

Key: N = No; N* = Generally no, unless under special circumstances; Y = Yes; Y* = Yes because no alternative exists; * = Possible if the activity can be managed so that it is compatible with protected site objectives.

Table 2: Sensitivity of specific habitat features in English MPAs (e.g. Poole Harbour EMS) to pressures from bottom shellfish aquaculture, demersal trawling and maintenance dredging

Pressure Name	Bottom shellfish aquaculture													Demersal trawling													Maintenance dredging												
	Coastal lagoons	Coastal reedbeds	Grazing marsh	Halophilous scrubs	Salicornia and other annuals	Atlantic salt meadows	Spartina swards	Intertidal seagrass beds	Intertidal mixed sediments	Intertidal mud	Intertidal sand and muddy sand	Water column	No. sensitive habitats/pressure	Coastal lagoons	Coastal reedbeds	Grazing marsh	Halophilous scrubs	Salicornia and other annuals	Atlantic salt meadows	Spartina swards	Intertidal seagrass beds	Intertidal mixed sediments	Intertidal mud	Intertidal sand and muddy sand	Water column	No. sensitive habitats/pressure	Coastal lagoons	Coastal reedbeds	Grazing marsh	Halophilous scrubs	Salicornia and other annuals	Atlantic salt meadows	Spartina swards	Intertidal seagrass beds	Intertidal mixed sediments	Intertidal mud	Intertidal sand and muddy sand	Water column	No. sensitive habitats/pressure
Abrasion/disturbance of the seabed surface	S							S	S	S	S		5								S	S	S	S		4	S				S	S	S	S	S	S	S		8
Changes in suspended solids (water clarity)	S							S	S	S	S	S	6								S	S	S	S	S	5	S				S	S	S	S	S	S	S	S	9
Introduction or spread of INIS	S							S	S	S	S	S	6								S	S	S	S	S	5	S				S	S	S	S	S	S	S	S	9
Penetration and/or disturbance below the seabed surface	S							S	S	S	S		5								S	S	S	S		4	S				S	S	S	S	S	S	S		8
Removal of non-target species	S							S	S	S	S		5					NS	S	IE	S	S	S	S	S	6													
Smothering and siltation rate changes (Light)	S							S	S	S	S		5								S	S	S	S		4	S				NS	NS	NS	S	S	S	S		5
Visual disturbance											NS	S	1											NS													NS	S	1
Deoxygenation	S							NS	S	NS	S	S	4					NS	NS	NS	NS	S	NS	S	S	3	S				NS	NS	NS	NS	S	NS	S	S	4
Hydrocarbon & PAH contamination	NA							NA	NA	NA	NA	NA						NA	NA	NA	NA	NA	NA	NA	NA		NA				NA	NA	NA	NA	NA	NA	NA	NA	
Introduction of light	S							S	IE	NS	S	S	4								S	IE	NS	S	S	3	S							S	IE	NS	S	S	4
Litter	NA							NA	NA	NA	NA	S	1					S	S	S	NA	NA	NA	NA	S	4													
Nutrient enrichment	NS							S	NS	NS	NS	S	2					NS	NS	NS	S	NS	NS	NS	S	2	NS				NS	NS	NS	S	NS	NS	NS	S	2
Organic enrichment	S							S	NS	NS	NS	S	3					NS	NS	NS	S	NS	NS	NS	S	2													
Physical change (to another sediment type)	S							S	S	S	S		5					S		S	S	S	S	S		6	S				S	S	S	S	S	S	S	S	9
Synthetic compound contamination	NA							NA	NA	NA	NA	NA						NA	NA	NA	NA	NA	NA	NA	NA		NA				NA	NA	NA	NA	NA	NA	NA	NA	
Transition elements & organo-metal contamination	NA							NA	NA	NA	NA	NA						NA	NA	NA	NA	NA	NA	NA	NA		NA				NA	NA	NA	NA	NA	NA	NA	NA	
Underwater noise changes												S	1												S	1												S	1
Total no. of habitat features sensitive to each pressure for each activity													53													49													60
Totla number of times ranked most sensitive													0													0													0

'Genetic modification and translocation of indigenous species' and the 'Introduction of microbial pathogens' are peculiar to aquaculture and therefore these were not comparable across marine activities.

5.2.4) Refining compatibility assessments for mariculture and MPAs

Additional steps necessary for refining compatibility assessments for mariculture and MPAs include: establishing local baselines in feature condition; predicting the effects of proposed mariculture species and technologies through extrapolations from other comparable areas; accounting for the location and spatial scale of proposed operations; understanding interactions between mariculture and other competing marine pressures and uses (alongside the conservation of protected features) (Le Gouvello et al., 2017; IUCN, 2020). In offshore areas there is additional scope to optimise conditions for mitigating aquaculture impact based on guidelines for minimum water depth (twice the depth of mariculture infrastructure) and minimum water flow rates (>0.05 m/s) (Belle and Nash, 2008; Froehlich et al., 2017).

There is considerable uncertainty relating to the condition (favourable or non-favourable) and extent of some MPA features in England and the rest of the UK, which confounds the assessment of potential impacts on MPAs from marine activities. This is particularly the case for sedimentary habitats, which represent the areas of highest fishing activity in England and the rest of the UK (JNCC, 2020) and, based on generic sensitivity matrices, have greatest potential for mariculture development. UK Government has committed to an ambitious programme of condition monitoring for all designated sites.

Where sites lack condition assessments, an alternative approach will be to use feature × activity 'vulnerability assessments' (outlined above), but these don't account for background factors, such as storm events. Vulnerability assessments began with the designation of Marine Conservation Zones (under the UK Marine and Coastal Access Act) in Tranche 1 in 2016. Inshore Fisheries Conservation Authorities (IFCAs) have completed 74 assessments of feature/activity interactions (focusing mainly on fishing activities) while a further 186 are currently in progress or at quality assurance stage. In future, a lower reliance will be placed on vulnerability assessments, as further monitoring surveys take place to inform understanding of the condition of the features within the network (DEFRA, 2018b).

Substantial work is also required to understand and quantify environmental interactions between mariculture developments and feature within MPAs, and to quantify uncertainty when extrapolating from one MPA to another (IUCN, 2020).

5.2.5) Transformative policies and approaches for enabling sustainable mariculture development in and around MPAs

There is a long history of sustainable management of mariculture in MPAs through the use of Regulating Orders and Several Orders and Byelaws administered by the IFCAs (Seafish, 2016). However, the development of new mariculture sites in and around MPAs is highly challenging due to the precautionary approach currently taken to protect all designated features from significant adverse effects.

Transformative policies and approaches for enabling sustainable mariculture development in and around MPAs will hinge on differentiating sites and constituent features based on their conservation importance and sensitivities to different forms of mariculture. This will allow for the sharing of space within compatible sites, sub-zones and/or peripheral buffer zones (i.e. Allocated Zones for Aquaculture 'AZA' and Allowable Zones of Effect 'AZEs'), in which mariculture presents insignificant risks to the achievement of MPA conservation objectives (Sanchez-Jerez et al., 2016).

Publication of Defra's (2012) 'revised approach' for the assessment and management of fishing activities in European Marine Sites represented a key milestone in policy development which is highly relevant to mariculture development (DEFRA, 2012). Rather than placing a blanket ban on fishing in MPAs, the revised approach focused on regulating activities most likely to impact on the most vulnerable sites and features, with reef features and bottom-towed gear being identified as priorities (JNCC, 2020). In areas where fishing activities are deemed to be compatible with MPAs according to DEFRA's matrix of fishing gear types and European Marine Site protected features (**Appendix 2**), an 'ecosystem-based approach' is advocated to ensure MPA conservation objectives are met without disproportionately impacting on fishing activity (Levin et al., 2018). This can be achieved using a both a 'zonal' approach and 'adaptive risk management' (**Table 3**), which adapts fisheries management based on ongoing monitoring and assessment in areas where the evidence of impacts is uncertain.

Adaptive risk management takes into account: conservation feature extent and distribution; feature condition and sensitivity to the specified activity; spatial distribution and intensity of the activity; evidence on other background pressures on conservation features; trends indicating whether features are progressing towards achieving their conservation objectives. The zonal approach is entirely consistent with whole-site ecosystem-based approach for preserving the integrity, structure and function of MPAs alongside mariculture developments (**Table 3**).

Despite the transformative potential of these policies and approaches, it is unlikely that the current levels/frequencies of feature condition monitoring undertaken by JNCC and Natural England will meet the necessary spatio-temporal monitoring resolution required for adaptive management or zonal management.

Table 3: Complementary elements of adaptive risk management and zonal management relating to sustainable mariculture development in and around MPAs

Adaptive risk management	Zonal management
Relies on ability to monitor and detect change in order to inform adaptive measures	***Relies on ability to identify MPA zones that are compatible with different forms of mariculture***
Conduct monitoring, modelling and mapping of conservation feature extent and distribution	Account for the geographic coverage of habitat features within MPAs
Gather information/evidence on feature condition and sensitivity to different forms of mariculture	Where possible locate mariculture activity in large areas of continuous feature rather than smaller, fragmented areas
Gather information/evidence on activities - spatial distribution and intensity	Zoning should be designed in a transparent and inclusive manner engaging all stakeholders
Determine trends – whether features are progressing towards achieving their conservation objectives	Maintain long-term monitoring at key sites to evaluate positive and negative impacts on MPAs/ features
Gather information/evidence on other background pressures on conservation feature	Combining monitoring evidence with experiments such that decisions about changing measures through adaptation are not only made on a site by site basis.

Adaptive and zonal management represent refinements to feature-based approaches for managing MPAs and activities within them (including mariculture). All approaches require ongoing monitoring to detect changes in habitat feature condition, and to determine whether or not changes are attributable to specific activities (or background factors e.g. climate change).

5.3) Case study

5.3.1) Mapping of existing mariculture sites in SW England

Mapping of existing shellfish and seaweed mariculture sites in SW England has shown that over 70% of aquaculture sites are located within MPAs. Collectively these MPAs contain the full range of habitat features listed in Annex 1 of the Habitats Directive (**Table 4**). The majority (~90%) of sites located within MPAs were licenced prior to MPA designation. Apart from current concerns around Invasive

Non-Indigenous Species (i.e. feral Pacific oysters, *Magallana gigas* populations in the Tamar and Yealm estuaries), mariculture operations in general in SW England have not been shown to impact negatively on MPA features. This is according to feature condition monitoring or site vulnerability assessments conducted by Natural England. Mariculture has been shown to be compatible with some designated habitat features. For example, Poole Harbour has supported a thriving shellfish mariculture industry, managed via a Several Order since 1915. Currently 24% of the Poole Habour MPA (Special Protection Area, SSSI, Ramsar Site) is leased for bottom-culture of shellfish (blue mussels, Pacific oysters, edible cockles and Manilla clams) – the development exists on sub-tidal mud, away from sensitive species and habitats such as seagrass beds (*Zostera marina*), peacock worms (*Sabella pavonina*) and internationally important populations of intertidal wading birds.

Despite the considerable precedent for the long-term sustainable operation of shellfish mariculture sites in MPAs, licencing of new aquaculture developments in these areas is impeded by rigid regulation founded on the precautionary principle (**Section 5.2.1**).

Table 4: Proportion of SW Mariculture sites located within MPAs with habitat features (listed in Annex 1 of the Habitats Directive)

MPAs	Aquaculture sites (n=21)		
	within MPAs	< 1km	>1km
○ SACs	9 (39%)	1 (4%)	1 (4%)
○ SPAs	3 (13%)		
○ SSSIs	4 (17%)	1 (4%)	
○ MCZs	5 (22%)	1 (4%)	
○ All above	17 (74%)	3 (13%)	1 (4%)

20 (87%)

Marine habitat features (Annex 1)

Mud sandflats (intertidal)	Sandbanks (subtidal)	Atlantic salt meadows	L shallow inlets & bays	Coastal Lagoons A	Sea caves	Estuaries	Reefs B
✓	✓	✓	✓	✓	✓	✓	✓
✓	✓	✓	✓	✓	✓	✓	✓
All the above and more							
All the above and more							
							11

(52%)

5.3.2) Detailed mapping of areas suitable for mariculture development along the Dorset and East Devon coastline by CEFAS

CEFAS undertook to identify and map areas best suited (and with least conflict) to specific types of sustainable marine aquaculture, within the boundaries of the Dorset and East Devon Fisheries Local Action Group (FLAG) area, extending from Beer Head to Poole Entrance, out to 6 nm limit from the coast. A comprehensive set of spatial data, from a number of different sources, was compiled for analysis, processing and mapping of aquaculture suitability extents within the area; these included a range of environmental suitability criteria taken from the Horizon 2020 'AquaSpace' project (Boogert et al., 2018). Environmental variables underpinning aquaculture suitability (water depth, substrate, exposure to currents, water quality etc.) were classified in optimal, suboptimal and unsuitable ranges based on published literature. Mariculture potential was then determined for each culture species based on an appropriate culture method for the area. Where areas suitable for mariculture overlapped with other marine activities (anchorages, transport routes, leisure, communication, dredging, historical sites, sewage effluent discharges etc.), these were treated as exclusion zones, including buffer zones ranging from 0.5 to 2 km around the activity (depending on the scale of activity). Suitable areas were not excluded when they overlapped with fishing areas or MPAs; here it was assumed that developments would need to be assessed on a case by case basis. Stakeholder consultation workshops (additional to the original project scope) were undertaken to review draft maps of areas with potential for aquaculture within the FLAG district. Feedback from these has been incorporated into both final maps of aquaculture potential available on Dorset and East Devon Aquaculture site https://www.dorsetaquaculture.co.uk/opportunities/new/map/; the CEFAS data hub http://data.cefas.co.uk/ and a final report (Kershaw et al., 2020).

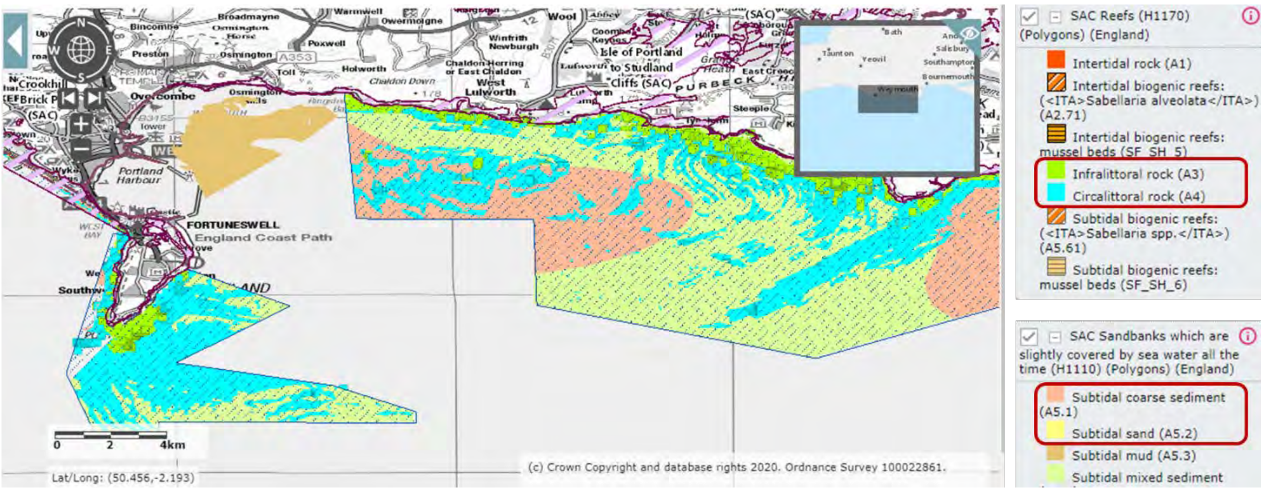
This CEFAS report adds significantly more resolution to previous work to identify areas of aquaculture potential in English waters (Heal and Capuzzo, 2019) and addresses many of the recommendations made in a critical review of the initial MMO report (Franco et al., 2017). Whilst some work has begun on clarifying the compatibilities of mariculture and MPAs, there is an ongoing recommendation for further work to define compatibilities with different habitat feature types within MPAs (Kershaw et al., 2020).

As a minimum, the distribution of habitat features within the FLAG area and individual MPAs was defined using the JNCC UKSeaMap 2018 broad-scale vector layer. Habitats included Annex 1 habitats (intertidal substrate & foreshore (mud, sand, gravel, boulders, rock); mudflats; saltmarsh; maritime cliffs & slope; coastal vegetated shingle; coastal sand dunes). In some areas the location and extent of habitat features was captured to a higher resolution by multi-beam echo sounding, drop camera, diving and remote grabbing surveys e.g. in the Lyme Bay and Torbay SAC ID UK0030372 (31248 ha)

(Munro & Baldock, 2012; Wood, 2007) and the DORset Integrated Seabed study incorporating the Studland to Portland SAC ID UK0030382 (33191 ha) https://www.dorsetwildlifetrust.org.uk/doris.

Currently less than 0.3 % of the sea area in the East Devon and West Dorset FLAG area (to 6 nautical miles offshore) is used for aquaculture production. Notwithstanding other competing resource and planning constraints and within the resource limitations of the project, and on the basis of detailed research from best available information and modelling work reported on here; 68% of the total sea area within this FLAG sea area was found to have optimal aquaculture potential for one or more marine species and ~28% of suitable area occurs within MPAs (**Figure 2**). There remains a potential conflict between mariculture and fishing in most of the suitable areas identified.

Figure 2: Map of MPAs, underlying habitats and areas suitable for mariculture development



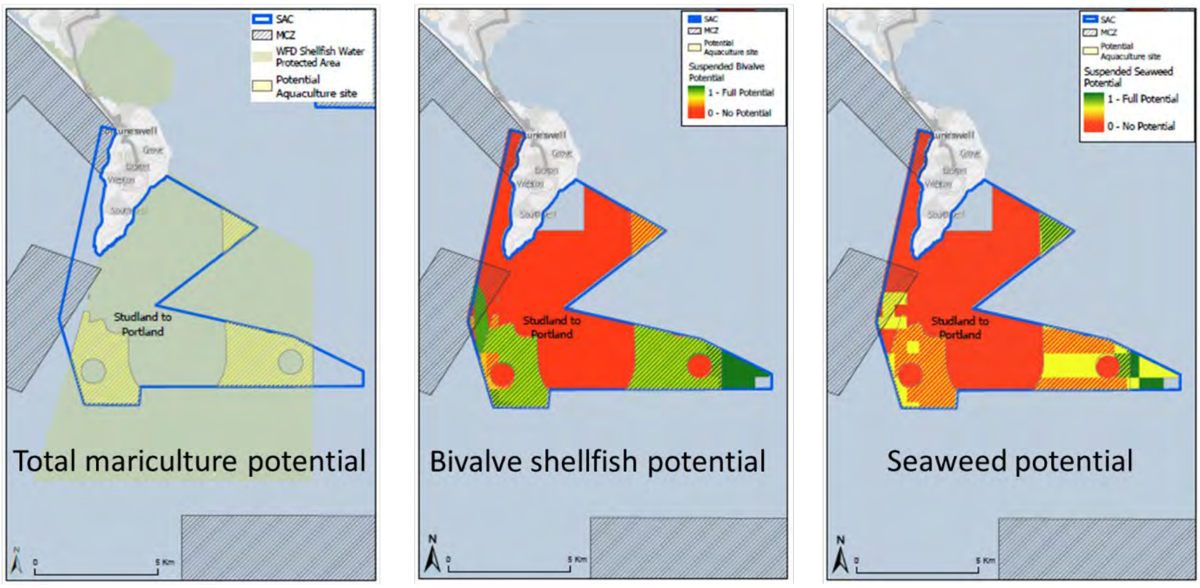
For the purpose of defining the importance of specific sensitive habitat features within MPAs to allow for the compatibility assessment and 'zoning' of different forms of mariculture, detailed mapping of conservation features and areas of mariculture potential around the Portland Reefs section of the Studland to Portland SAC (surrounding Portland Bill) (**Figure 3**) were compiled for presentation at the multi-stakeholder workshop (**Section 5.4**). Portland Reef is characterised by flat bedrock, limestone ledges, large boulders and cobbles, which extend underwater to >60m. This mosaic of reef habitats are exposed to extremely strong tides, currents and wave action, and support a diverse range of marine life, including Mussel (*Mytilus edulis*) beds and kelp (*Laminaria* and *Saccharina* forests (Cork et al., 2008), (Dewey et al., 2011), (Natural England, 2009).

In the FLAG mapping exercise, reef habitats were considered to be vulnerable marine ecosystems within the Natura 2000 sites (SACs or SPAs), which are restricted to towed demersal fishing gear according to Marine Spatial Planning guidelines https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file

/841305/191023_MMO1172_Evaluation_of_MPA_Measures_publication.pdf. Reef areas were excluded from areas defined for aquaculture potential, which instead focused on subtidal sand and gravel (which are not restricted to towed demersal fishing gear).

The concept of deploying mariculture methods, for example, farming of blue mussels, or kelp, in zones occupied by these habitat features within MPAs was discussed at the multi-stakeholder workshop. The need to define acceptable thresholds (benchmarks) for assessing the sensitivity of mariculture practices to reefs was highlighted. Comparative benchmarking could be taken from work undertaken on shellfish potting, which has been shown to have minimal impact on reefs in the Lyme Bay SAC (Rees et al., 2019).

Figure 3: Mapping of habitat features and areas suitable for mariculture development around Portland Reef



5.4) Multi-stakeholder workshop

Stakeholder consultation during the workshop was based around four illustrative case studies. Case studies focused on SW England and were used to emphasise the evidence and planning issues that need to be addressed to allow for mariculture development across England. Key points are summarised below and reported in detail separately (Daniels et al., 2020).

5.4.1) Case study 1: Seafood 2040 - The English Aquaculture Strategy

Seafood 2040 provides a strategic framework for sustainable seafood production and consumption in England (SeaFish, 2017), which will be delivered in part through the English Aquaculture Strategy. This strategy will focus on establishing clear channels of communication between marine users (industry and domestic stakeholders) and regulators, in order to ensure that aquaculture development is environmentally and socially sustainable. Mariculture has the potential to restore and enhance marine environments if appropriately located, as well as contribute to local economies. Evidence to demonstrate this potential is required for novel and emerging aquaculture developments, and this may be provided by pilot projects and test beds, though the temporal and spatial scale of these projects and therefore their relevance may be limited. The ability to extrapolate from one area or test bed to another also needs to be considered.

A general conclusion from Case Study 1 was that regulation needs to be adapted to better facilitate mariculture development; a clearer, simpler regulatory process and more human resources are required to allow this to happen.

5.4.2) Case study 2: Sustainable mariculture development - sharing sea space, avoiding conflict & protecting the environment

The Inshore Fisheries and Conservation Authorities (IFCAs) are responsible for managing sustainable development of mariculture and fisheries within their given districts. The Devon and Severn district is a hive of marine activity, over 1000 permits are issued to commercial and recreational fishermen and there is a squeeze on additional fishing opportunities. New mariculture licences require a thorough assessment of potential conflict and the absence of this information can slow down regulatory processes. To combat this, the IFCA is developing a mariculture strategy that takes into account all influencing factors and evidence on existing space use within the Devon and Severn district. Central to the strategy is the incorporation of up-to-date spatial maps that can be used to highlight opportunities for sustainable development without increasing conflict with other users. These include a potential aquaculture park within Torbay, and other areas within North Devon where there is less fishing pressure.

There is an opportunity for aquaculture businesses to engage with members of the fishing industry early on in order to strengthen applications. Importantly, any developer should to try and engage with local fishers to evidence how they can benefit from the site rather than risk removing fishing opportunities. Remaining transparent and keeping an open mind on how the two industries can integrate is essential.

5.4.3) Case study 3: Mariculture developments in and around MPAs in England

There is an urgent need to reconcile sustainable development with nature conservation and – in the case of mariculture – understand the impacts and ecosystems services associated with novel and emerging approaches. In SW England over 70% of aquaculture sites are located within MPAs, with sites being zoned to ensure that sensitive habitat features are unaffected. For example, 24% of the Poole Harbour Special Area of Conservation is leased for bottom-aquaculture – the development exists on sub-tidal mud, where activities don't interfere with wading birds, and they are away from sensitive species and habitats such as seagrass beds and peacock worms. The presence of sensitive marine habitat features can influence the decision to permit a new aquaculture development.

There is a need to understand impacts of mariculture on habitat features, to ascertain where positive and negative impacts may occur. Such data can be used to create a risk matrix with detailed mapping in order to identify areas that are compatible with mariculture development. With this in place, it will be possible to complete relatively rapid assessments of new developments and start developing general rules for initial screening of license applications in and around marine protected areas.

5.4.4) Case study 4: Regulatory processes for aquaculture

Mariculture licensing sits under Section 66 of the Marine and Coastal Access Act. The licensing process is managed by the Marine Management Organisation (MMO) and includes a number of stages, starting with initial scoping and consideration of impacts on fisheries and other uses of the area, to sensitive sites and archaeological remains. Fish and shellfish mariculture require Environmental Impact Assessment (EIA) screening, whereas the culture of algae is exempt, but licence applications can still be refused on environmental grounds. Applications up to 1 nautical mile from shore, must submit Water Framework Directive Assessment. Furthermore, a Habitats Regulations Assessment is required to assess potential impacts on all conservation features within European Marine Sites. The MMO are moving towards plan-led licensing, with remaining marine plans to be adopted by 2021.

The MMO's 'Explore Marine Plans' tool (https://www.gov.uk/guidance/explore-marine-plans) can be used to locate strategic sites for sustainable aquaculture development in England's coastal waters. The tool is being further developed to include a broader range of environmental constraints, such as water quality, nutrient load and primary productivity. However, additional spatial resolution and specificity are needed for optimising the use of marine space i.e. distinguishing areas that are suitable for different forms of aquaculture (Kershaw et al., 2020).

6) CONCLUSIONS

- There is considerable potential to develop mariculture in England, as an environmentally sustainable form of food production, however this is restricted by the limited available marine space, particularly in territorial coastal waters, due to extensive MPAs, fishing areas, and other coastal users.
- Shellfish and seaweed mariculture, which utilise natural sources of plankton and nutrients, are compatible with some habitats/ conservation features within MPAs. Mariculture techniques for finfish currently adopted in the UK are less compatible with MPAs, due to the use and potential impact of fish feed and veterinary medicines.
- The majority (>70%) of mariculture (predominantly shellfish mariculture) sites in SW England are located within MPAs and have been shown over time (in some cases for over 100 yrs) to be:
    - Compatible with some habitat features e.g. mud, sand and gravel habitat (having negligible impact on their condition);
    - Sustainably and efficiently managed through a range of fisheries orders and byelaws.
- Habitat features which are considered less compatible with mariculture include reefs, which are classified as vulnerable marine ecosystems in Marine Spatial Plans. The use of towed demersal fishing gear is restricted around these features, but there is accumulating evidence of negligible impact from deployment of static gear, such as crab pots, which are more comparable to suspended mariculture systems.
- Current levels of feature condition monitoring (for assessing MPA status) are generally insufficient for traditional feature-based and alternative zonal ecosystem-based licensing and management of mariculture sites.
- Clearer specification of what constitutes a significant adverse effect on MPA feature condition is required, as well as more accurate tools for quantifying the contribution of mariculture developments towards any (cumulative) adverse effects.
- Licencing of new mariculture sites within MPAs is impeded by traditional precautionary feature-based conservation approaches.

7) RECOMMENDATIONS

Licencing of new mariculture sites should be based on zonal ecosystem-based approaches, as advocated in DEFRA's 25 year plan.

To help identify Allocated Zones for Aquaculture in England's intensely crowded coastal waters, including within MPAs The following tools need to refined and applied:

- Habitat feature-based sensitivity matrices for prospective assessment of the suitability of different types of marine aquaculture:
    - Feature-specific risk assessment should be refined, building on Natural England's (generic) risk matrices and environmental monitoring data from existing sites quantifying aquaculture × MPA feature interactions.
    - General rules for the screening of proposed marine aquaculture developments should be established, based on learning gained from risk matrices and environmental monitoring data.
- Adaptive risk management of ongoing aquaculture developments (pilot studies) and operations:
    - Marine aquaculture developments and site operations in and around MPAs should be informed by evidence gathered from ongoing monitoring of habitat features in relation to planned and implemented aquaculture activities.
    - Comparing evidence from monitoring of aquaculture sites and reference sites (e.g. HRA sites) will help elucidate trends in feature condition and impacts from other (background) pressures.
- Tools quantifying ecosystem service benefits provided by different forms of marine aquaculture, including habitat provisioning, coastal protection, nutrient regulation, carbon sequestration.
- A transparent decision making framework (informed by the above tools) for regulators and prospective marine aquaculture licensees (see Daniels et al., 2020; SeaFish, 2020).

ACKNOWLEDGEMENTS

The authors are very grateful to Roger Covey (Natural England) and Pia Bateman (Southern Inshore Fisheries Conservation Authority) for their expert opinion and guidance and for providing links to a range of conservation planning resources for MPAs and mariculture referenced in this document. We are also grateful to Research England for funding this work through their Strategic Priorities Fund.

REFERENCES

Asche F, Smith MD (2018). Induced innovation in fisheries and aquaculture, Food Policy 76: 1–7.

Belle SM, Nash CE (2008). Better management practices for net-pen aquaculture, in Tucker CS, Hargreaves JA (eds). Environmental best management practices for aquaculture, pp 261–330, Wiley-Blackwell, Oxford, UK.

Boogert FJ, Cubillo AM, Nunes JP, Ferreira JG, Corner RA (2018). Online Environmental Feasibility Application (Deliverable 2.5) and Milestone MS15 Release of on-line Environmental Feasibility Application. URL: http://www.aquaspace-h2020.eu/wp-content/uploads/2018/09/Aquaspace-D2-5-WATER-v2Aug2018.pdf.

Brown AR, Lilley M, Shutler J, Lowe C, Artioli A, Torres R, Berdalet E, Tyler CR (2019). Assessing risks and mitigating impacts of harmful algal blooms on mariculture and marine fisheries. Reviews in Aquaculture 1–26 doi: 10.1111/raq.12403.

CBD, Convention on Biological Diversity (2010). The strategic plan for biodiversity 2011–2020 and the Aichi biodiversity targets. Document UNEP/CBD/COP/DEC/X/2. Nagoya, Japan: Secretariat of the Convention on Biological Diversity.

CEFAS, Centre for Fisheries and Aquaculture Science (2012). Fisheries in European Marine Sites: review of 'the matrix' and associated documentation submitted to the Stakeholder Implementation Group (IG). URL (accessed June 2020): https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/310814/cefas_matrix_review.pdf

Clements JC, Chopin T (2017). Ocean acidification and marine aquaculture in North America: potential impacts and mitigation strategies. Reviews in Aquaculture 9(4): 326-341.

Cork M, McNulty S, Gaches P (2008). Site Selection Report for the Inshore Marine SACs Project: Natural England.

Daniels C, Mynott S, Brown AR, Martin J, Ashton IG (2020). Supporting Mariculture Development - Evidence for Informed Regulation. Report for Research England, Strategic Priorities Fund to support Evidenced-Based Policy Making.

Day J, Dudley N, Hockings M, Holmes G, Laffoley D, Stolton S, Wells S (2012). Guidelines for applying the IUCN Protected Area Management Categories to Marine Protected Areas. Gland, Switzerland: IUCN. 36pp.

DEFRA (2012). Revised approach to the management of commercial fisheries in European marine sites in England: Project Implementation Plan. Defra. Available ONLINE http://webarchive.nationalarchives.gov.uk/20140305091040/http://www.marinemanagement.org.uk/protecting/conservation/documents/ems_fisheries/pip.pdf

DEFRA (2015). United Kingdom multiannual national plan for the development of sustainable aquaculture, October 2015. URL (accessed May 2020): https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/480928/sustainable-aquaculture-manp-uk-2015.pdf

DEFRA (2018a). HM Government: A Green Future: Our 25 Year Plan to Improve the Environment Annex 1: Supplementary Evidence Report 145. URL (accessed July 2020):

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/673492/25-year-environment-plan-annex1.pdf

DEFRA (2018b). Marine Protected Areas Network Report 2012 – 2018. Presented to Parliament pursuant to Section 124 of the Marine and Coastal Access Act 2009. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/765418/mcaa-mpa-report-2012-2018a.pdf

DEFRA (2019). HM Government: A Green Future: Our 25 Year Plan to Improve the Environment Department for the Environment Food and Rural Affairs, London https://www.gov.uk/government/publications/25-year-environment-plan

Dewey S, Axelsson M, Plastow L (2011). DORset Integrated Seabed Survey (DORIS) Identifying Dorset's Marine Conservation Features, Drop Down camera ground truthing survey report: Sea Star Survey.

EEA European Environment Agency (2107) Aquaculture production - Indicator Assessment ID: IND-25-en (CSI 033 , MAR 008). Published 07 Jun 2018. URL (accessed 6/8/2017): https://www.eea.europa.eu/data-and-maps/indicators/aquaculture-production-4/assessment

EC, European Commission (2012). Guidance document on aquaculture activities in the context of the Natura 2000 network. URL (accessed July 2020): https://ec.europa.eu/fisheries/sites/fisheries/files/docs/body/guidance-aquaculture-natura2000.pdf

FAO, Food and Agriculture Organisation (2009). Marine Protected Areas as a Tool for Fisheries Management. About MPAs. FI Project Websites. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 1 July 2009. URL (accessed June 2020): http://www.fao.org/fishery/topic/4400/en

FAO, Food and Agriculture Organisation (2020). The State of the World Fisheries and Aquaculture 2012. FAO Fisheries and Aquaculture Department. FAO. URL (accessed June 2020): http://www.fao.org/3/ca9229en/ca9229en.pdf

Franco SC (2017). Developing the MMO model for mapping aquaculture potential. Analysis of model MMO 1040 and recommendations for improvement. Valuing Nature Placement. Deliverable 1. https://www.seafish.org/media/1758345/acig_april2018_aquaassessment_marineplanning.pdf.

Froehlich HE, Smith A, Gentry RR, Halpern BS (2017) Offshore Aquaculture: I Know It When I See It. Frontiers in Marine Science 4:154. doi: 10.3389/fmars.2017.00154

Gentry RR, Froehlich HE, Grimm D, Kareiva P, Parke M, Rust M (2017) Mapping the global potential for marine aquaculture. Nature Ecology and Evolution 1: 1317-1324.

Hall K, Paramour OAL, Robinson LA, Winrow-Giffin A, Frid CLJ, Eno NC, Dernie KM, Sharp RAM, Wyn GC, Ramsay K (2008). Mapping the sensitivity of benthic habitats to fishing in Welsh waters - development of a protocol CCW (Policy Research) Report No: 8/12. Bangor, Countryside Council for Wales (CCW). pp. 85.

Heal R, Capuzzo E (2019). Identification of Areas of Aquaculture Potential in English Waters, MMO Project No: 1184, May 2019, 109 pp.

Humphreys J, Clark RWE (2020). A critical history of marine protected areas. In Eds Humphreys J and Clarke RWE, Marine Protected Areas - Science, Policy and Management 2020, Pages 1-12, Publ. Elsevier, London.

IUCN, International Union for the Conservation of Nature (2020). Aquaculture and Marine Protected Areas: Exploring Potential Opportunities and Synergies. URL (accessed July 2020): https://www.iucn.org/sites/dev/files/content/documents/aquaculture_and_marine_protected_areas.pdf

JNCC, Joint Nature Conservation Committee (2019). UK Marine Protected Area network statistics. URL (accessed July 2020): https://jncc.gov.uk/our-work/uk-marine-protected-area-network-statistics/

JNCC, Joint Nature Conservation Committee (2020). MPA Fisheries Management Toolkit. URL (accessed May 2020): http://data.jncc.gov.uk/data/da4ae34c-d0f3-41df-b4fd-79df0a079647/MPA-Fisheries-Management-Toolkit-FINAL.pdf

Kapetsky JM, Aguilar-Manjarrez J, Jenness J (2013). A global assessment of potential for offshore mariculture development from a spatial perspective. FAO Fisheries and Aquaculture Technical Paper. No. 549. Rome, FAO. 181 pp.

Kershaw, S., Beraud, C., Heal, R., Posen, P., Tew, I. and Jeffery, K. (2020). Mapping of Areas of Potential Aquaculture within the Dorset and East Devon Fisheries Local Action Group (FLAG) area. Cefas Contract C7731, European Maritime and Fisheries Fund (EMFF) grant number ENG3016, pp. 1-187.

Le Gouvello R, Hochart L-E, Laffoley D, Simard F, Andrade C, Angel D, Callier M, De Monbrison D, Fezzardi D, Haroun R, Harris A, Hughes A, Massa F, Roque E, Soto D, Stead S, Marino G (2017). Aquaculture and marine protected areas: Potential opportunities and synergies. Aquatic Conservation: Mar Freshw Ecosyst. 27(S1):138–150.

Levin PS, Essington TE, Marshall KN, Koehn LE, Anderson LG, Bundy A, Carothers C, Coleman F, Gerber LR, Grabowski JH, Houde E, Jensen OP, Möllmann C, RoseK, Sanchirico JN, Smith ADM (2018). Building effective fishery ecosystem plans. Mar. Pol., 92: 48-57.

MSFD (2008). http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-frameworkdirective/index_en.htm

MMO, Marine Management Organisation (2018). UK Sea Fisheries Statistics 2017. URL (accessed June 2020): https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/742793/UK_Sea_Fisheries_Statistics_2017.pdf

Möckel (2017). The assessment of significant effects on the integrity of "Natura 2000" sites under Article 6(2) and 6(3) of the Habitats Directive. Nature Conservation 23: 57-85.

Muir J (1992). Water management for aquaculture and fisheries; irrigation, irritation or integration? In Priorities for Water Resources Allocation and Management pp 127-148, Publ. Overseas Development Administration, ISBN: 090 2500 49X.

Munro, C. D., and Baldock, B. M. (2012). Lyme Bay Closed Area - Measuring Recovery of Benthic Species in cobble reef habitats – analysis of data collected by SCUBA divers September 2008, August 2009 and July 2010. A Marine Bio-images report, February 2012, Marine Bio-images, Exeter, Devon, UK, pp 38. URL (accessed June 2020): https://www.lymebayreserve.co.uk/download-centre/files/Lyme_Bay_Closed_Area_Monitoring_2008-2010_MBI.pdf.

Natural England (2009). Inshore special area of conservation (SAC) Poole Bay to Lyme Bay pSAC Selection Assessment Natural England.

Rees A, Sheehan EV, Attrill MJ (2018). The Lyme Bay experimental potting study: A collaborative programme to assess the ecological effects of increasing potting density in the Lyme Bay Marine Protected Area. A report to the Blue Marine Foundation and Defra, by the Marine Institute at the University of Plymouth.

Rees SE, Sheehan EV, Stewart BD, Clark R, Appleby T, Attrill MJ, Jonese PJS, Johnson D Bradshaw N, Pittman S, Oates J, Solandt J-L (2020). Emerging themes to support ambitious UK marine biodiversity conservation. Marine Policy 117, 103864.

Rodmell DP, Caveen AJ, Johnson ML (2020). Uneasy bedfellows: Fisheries and the search for space for Marine Conservation Zones in English waters. In Eds Humphreys J and Clarke RWE, Marine Protected Areas - Science, Policy and Management 2020, Pages 92-112, Publ. Elsevier, London.

Ross LG, Telfer TC, Falconer L, Soto D, Aguilar-Manjarrez JA (2013). Site selection and carrying capacities for inland and coastal aquaculture. FAO Fish Aquacult Proc No. 21. FAO, Rome.

Sanchez-Jerez, P., Karakassis, I., Massa, F., Fezzardi, D., Aguilar-Manjarrez, J., Soto, D., … Dempster, T. (2016). Aquacultures struggle for space: The need for coastal spatial planning and the potential benefits of allocated zones for aquaculture (AZAs) to avoid conflict and promote sustainability. Aquaculture Environment Interactions, 8: 41–54.

SeaFish (2016). SR695 UK Shellfish Production and Several, Regulating and Hybrid Orders: The Contribution and Value of Orders in Relation to the Sector's Past Development and Future Growth. URL (accessed May 2020): https://www.seafish.org/media/publications/FINAL_SRO_REPORT_-_AUGUST_2016_FINAL.pdf

SeaFish (2017). Sea Food 2040 – A strategic framework for England. URL (accessed May 2020): https://seafish.org/media/Seafood%202040%20strategic%20framework.pdf

Solandt J-L, Mullier T, Elliott S, Sheehan E (2020). Managing marine protected areas in Europe: Moving from 'feature-based' to 'whole-site' management of sites. In Eds Humphreys J and Clarke RWE, Marine Protected Areas - Science, Policy and Management 2020, Pages 157-181, Publ. Elsevier, London.

Southern IFCA, Inshore Fisheries Conservation Authority (2020). Southern Inshore Fisheries and Conservation Authority Poole Harbour Several Order 2015 Management Plan (2020 revision).

Tillin, H.M., Hull, S.C. & Tyler-Walters, H., 2010. Development of a sensitivity matrix (pressures-MCZ/MPA features). Report to the Department of the Environment, Food and Rural Affairs from ABPmer, Southampton and the Marine Life Information Network (MarLIN) Plymouth: Marine Biological Association of the UK., Defra Contract no. MB0102 Task 3A, Report no. 22., London, 145 pp. http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=16368

Tillin, H. & Tyler-Walters, H., 2014. Assessing the sensitivity of subtidal sedimentary habitats to pressures associated with marine activities. Phase 2 Report – Literature review and sensitivity assessments for ecological groups for circalittoral and offshore Level 5 biotopes. JNCC Report No. 512B, 260 pp.

Tyler-Walters H, Tillin HM, d'Avack EAS, Perry F, Stamp T (2018). Marine Evidence-based Sensitivity Assessment (MarESA) – A Guide. Marine Life Information Network (MarLIN). Marine Biological Association of the UK, Plymouth, pp. 91. Available from https://www.marlin.ac.uk/publications

UK Government Office for Science (2017). Future of the Sea: Trends in Aquaculture. UK Foresight, Government Office for Science. URL (accessed July 2020): https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/635209/Future_of_the_sea_-_trends_in_aquaculture_FINAL_NEW.pdf

Villasante S, Rodríguez-González D, Antelo A, Rivero-Rodríguez S, Lebrancón-Nieto J (2013). Why are prices in wild catch and aquaculture industries so different? Ambio 42 (8): 937–950.

Ware S, Downie A-L (2020). Challenges of habitat mapping to inform marine protected area (MPA) designation and monitoring: An operational perspective. Marine Policy 111: 103717. https://doi.org/10.1016/j.marpol.2019.103717

Westbrook S (2017). The value of aquaculture to Scotland. June 2017 A Report for Highlands and Islands Enterprise and Marine Scotland. URL (accessed July 2020): http://www.hie.co.uk/ regional-information/ economic-reports-and-research/archive/value-of-aquaculture-2017.html

Wood, C. (2007). Seasearch surveys in Lyme Bay, June 2007, A Report to Natural England, 26 pp. URL (accessed June 2020): https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwjc_r7L4o_mAhVGTcAKHSQsCZcQFjAAegQIBBAC&url=http%3A%2F%2Fpublications.

APPENDIX 1: Consultation with CEFAS, Natural England and IFCA on 20 February 2020

Developing 'generic rules' and targeted advice to facilitate marine aquaculture (mariculture) development around MPAs in SW England

Project scoping/planning meeting with Roger Covey (Natural England), Keith Jeffery (CEFAS), Charles Tyler and Ross Brown (University of Exeter/ SAF).

Outline

This is a 2 month pilot/seed corn project proposal, recently submitted to Research England's Strategic Priorities Fund. The intention is that it will provide a proof of concept (based around the Dorset and East Devon Fisheries Local Action Group (FLAG) area, mapped by CEFAS (2020) that could lead to larger scale project(s) funded via the Seafood Innovation Fund (SIF) and/or Maritime and Fisheries Fund (MFF).

Project elements

1) Initial consultation with policy partners – consult with stakeholders up front to collate all relevant info, risk assessment/sensitivity/suitability matrices and mapping tools which can be used as a basis for facilitating aquaculture development around MPAs.

Action - All to add names of key stakeholder to Appended list. Invite all stakeholders to a workshop during the project – timing to be agreed.

- Risk assessment matrix should be based on the Marine Evidence based Sensitivity Assessment (MarESA) https://www.marlin.ac.uk/sensitivity/sensitivity_rationale CEFAS contact for environmental suitability matrices – Richard Heal.

- Mapping will be based on the high res' mapping of Dorset and East Devon FLAG area, incl. additional detail on the location of key conservation features within MPA habitats. CEFAS contact for mapping – Paulette Posen.

Action - Keith to forward mapping report, once approved by Sara Cattahan and Ruth Allin.

2) Compile a generic matrix indicating the sensitivity to aquaculture for habitats and designated conservation features within MPAs in the FLAG area

- Initial (generic) assessment of habitats and designated (sub)features will be made using Marine Evidence based Sensitivity Assessment (MarESA). https://www.marlin.ac.uk/sensitivity/sensitivity_rationale

- The assessment will incorporate:
    - CEFAS's matrix assessment of the feasibility of aquaculture operations based on environmental conditions (e.g. substrate and bathymetry) across the FLAG area
    - Natural England's 'Advice on Operations System', which includes advice on the sensitivity of designated site features and sub-features to Seaweed, Shellfish and Finfish aquaculture operations. https://designatedsites.naturalengland.org.uk/
    - MMO's Matrix of fisheries gear types and European marine site protected features. https://www.gov.uk/government/publications/fisheries-in-european-marine-sites-matrix

- Development and application of risk assessment methodologies incl. Retrospective Habitat Risk Assessments and zoning e.g. the Williamsburg Resolution relating to aquaculture and fish movements. http://www.nasco.int/pdf/far_aquaculture/AquacultureFAR_EnglandWales.pdf

- The assessment will also identify where there is insufficient evidence to assess sensitivity for specific conservation (sub)features and aquaculture operations.

3) Search for missing evidence relating to mariculture-MPA interactions in the FLAG area

- Undertake a targeted literature search for evidence following MarESA guidelines (Tyler-Walters, 2018). These sensitivity assessments are generic and NOT site-specific. They are based on the likely effects of a pressure on a 'hypothetical' population in the middle of its 'environmental range' taking into account the magnitude and duration of the pressure in relation to pressure benchmark levels.

- Begin to quantify positive/synergistic (as well as negative) interactions of aquaculture operations and habitats and (sub)features.

4) Undertake site-specific assessments of the sensitivity of selected MPAs and (sub)features to possible (technically feasible) aquaculture operations in the FLAG area

- Cover a range of MPAs and (sub)features – varying in complexity from single to multiple habitats and species of conservation concern.

- Take into account spatial extent and continuity of MPAs and (sub)features – using detailed mapping of MPAs and (sub)features (from CEFAS mapping of the FLAG area).

- Take into account spatial scales (and temporal scales including recoverability) of interactions with aquaculture systems.

5) Establish generic rules/ targeted advice for types and extent of mariculture development around MPAs

- Extend Natural England's 'Advice on Operations System' for aquaculture.

- Include advice/rules on permissible overlapping zones versus non-overlapping buffer zones.

6) Hold workshop to analyse results with partners and selected stakeholders, including DEFRA

7) Produce a policy brief (publish as a short communication)

APPENDIX 2: Matrix of fishing gear types and European Marine Site protected features

See Fisheries in EMS Matrix:

https://www.gov.uk/government/publications/fisheries-in-european-marine-sites-matrix

Under DEFRA's revised approach prioritisation of fisheries management in European Marine Sites 12 within nautical miles of the coast will be achieved by the use of a 'Matrix of fisheries gear types and European marine site protected features' in which the vulnerability of habitats/features (e.g. Intertidal and subtidal chalk reef) is assessed for different fishing activities.

MATRIX CATEGORIES:

RED - conservation objectives will not be achieved because of sensitivity to a type of fishing irrespective of feature condition, level of pressure, or background environmental conditions

AMBER - doubt as to whether conservation objectives for a feature will be achieved because of its sensitivity to a type of fishing, in all sites where that feature occurs – site-specific assessment and appropriate management required.

GREEN - achievement of the conservation objectives for a feature is highly unlikely be affected by a type of fishing activity, in all sites where that feature occurs, further action is not likely to be required, unless there is the potential for in combination effects.

BLUE - For gear types where there can be no feasible interaction between the gear types and habitat features, a fourth categorisation of blue is used, and no management action should be necessary.

sweep

Investing in Nature for Health
REPORT

Alternative funding mechanisms for green space

This report was produced in collaboration with our project partners.

Why this report matters

Since 2010, austerity has led to reduced local authority budgets and income for non-governmental organisations. As a result, there has been significant impact on the funding available for maintenance and management of green infrastructure as well as the provision of activities within these spaces. This conflicts with how, as a society, we increasingly value public green and blue spaces for health and wellbeing; something that has been particularly widely recognised during the current Covid-19 pandemic[1].

Despite some new government funding supporting pilot schemes which aim to promote these benefits[2], the current recession and probable future public funding restrictions mean it is more than likely that budgets for green infrastructure will continue to decrease and be insufficient to meet rising demand. There is a growing need, therefore, to understand and access the alternative mechanisms that exist to fund green infrastructure and the activities and interventions associated with them.

Who should read this?

This information is relevant for individuals and organisations who are involved in the management of green infrastructure, particularly those who are considering the health benefits of these spaces, whether from the environmental management, urban planning or public health sectors.

What is the report about?

Responding to our partners' needs to understand and secure alternative sources of funding, the SWEEP Investing in Nature for Health project developed this report. It provides a concise summary of the breadth of funding mechanisms available for green infrastructure and the activities provided in these spaces.

It includes examples of some traditional, but mainly alternative, funding streams, and presents case studies that highlight their successful application. The report also raises wider questions about what we value as a so-ciety and how we might achieve more creative, cross-sectoral and sustainable models of funding, suitable for different stakeholder groups and applicable at scale.

The report:

- defines seven categories of funding mechanisms (page 3);
- outlines different types of funding mechanism within each category (pages 4-9);
- presents case studies (pages 10-16);
- lists key resources (page 17).

Case studies were selected to show successful use of alternative funding mechanisms for green spaces. The mechanisms highlighted have the potential for wider application and long-term effectiveness[3,4].

[1] Day BH. (2020) *The value of greenspace under pandemic lockdown. Environmental Resource Economics, 76:1161-1185*.
[2] https://www.england.nhs.uk/personalisedcare/social-prescribing/green-social-prescribing/
[3] *London Green Spaces Commission reportsiness models for parks in the 21st century.*
[4] Nesta (2018) *Meet the Rethinking Parks innovators: Eight parks projects developing promising and innovative operating models.* London: NESTA.

Categories of funding mechanism

Alternative mechanisms for funding green space can be grouped into the following seven categories. The majority of these are suitable for funding both the development and upkeep of green space and the provision of activities within these spaces. Mechanisms within each category are explored further below.

Taxation

Standard local and national government taxation structures allocate funding to green infrastructure maintenance and interventions. There are a range of additional tax-related measures, however, that can provide specific support and additional income for these activities, such as location-specific taxes or business levies.

Income-generating opportunities and loans

Green infrastructure can be used for commercial purposes to generate income, through the provision of services e.g. sports grounds and events, or settings for cafés.

Alternative management structures

Management of green infrastructure can be moved from local authority control to structures such as charitable trusts. This opens access to new sources of funding and can allow for a more strategic approach to finance to achieve stable annual funding.

Planning and development opportunities

Wider development, often private, can fund green infrastructure, whether directly or through levies raised through planning legislation.

Ecosystem development/payment for ecosystem services

Environmental services and benefits, provided by green infrastructure, can be utilised to generate income.

Charitable giving and voluntary sector involvement

These range from small scale opportunities, such as those involving local communities as volunteers in green space, to the larger scale, including seeking out corporate or philanthropic investment.

Multi-agency opportunities

Working in partnership or collaboration, within or between organisations, offers opportunities to access specialist services and expertise, different funding sources, and achieve cost-savings.

Funding mechanism	Description
TAXATION	
Location specific tax	• Community tax: residents in close proximity to green space pay a small tax directly to the local authority to fund maintenance and use e.g. provision of activities. In a UK context, this is likely to be through council tax or service charges e.g. on a housing estate. • 'Tourist tax': tax for use of green space.
Business Improvement Districts (BIDs) (and Park Improvement Districts)	BIDs are defined areas in which all business are charged an extra tax (or levy) in addition to normal business rates; these are used to fund specific projects, which could be green infrastructure-focused, with benefits for these businesses.
Levy	Similarly to BIDs, large employers in close proximity to a green space are charged an additional tax to fund the space.
Precepts	Precepts are another form of levy: a legally binding instruction for the levying authority to collect a certain amount of council tax. They are relevant in the case of green spaces with wider significance, where several local authorities or other organisations might contribute to their funding.
Tax Increment Financing (TIF) or local tax re-investment programmes	TIF captures anticipated future increases in tax revenues for a set period and uses these to finance the improvements e.g. new green spaces or activities within spaces, which are expected to generate those taxes.
INCOME-GENERATING OPPORTUNITIES AND LOANS	
Sponsorship/naming rights	Offering the opportunity to sponsor or name a green space, or facilities within it, can be a one-off or recurring opportunity to raise money. They may be small-scale e.g. a fee to name a park bench or tree, or large-scale e.g. annual sponsorship of a space, or event/activity in a space, by a private company.
Events or special uses	Holding one-off activities or events in green space or charging for the use of green space for specific purposes e.g. weddings, events, natural burials.
Concessions	Charging the public to use facilities such as parking, tennis courts and pools. Selling products e.g. firewood.
Rental charges	Charging rental fees for retail opportunities in green spaces e.g. agricultural/grazing licenses, cafés, or for use of the park e.g. fitness groups larger than 3 people, professional dog walkers, forest schools.
Bonds	• Municipal: issued by local authorities to the capital market to fund capital expenditure such as the construction of infrastructure; essentially a loan by the investor e.g. pension funds, insurance companies. • Green/environmental impact: issued to fund projects with positive environmental benefits; in their simplest form, investors pay for the project and are repaid an amount based on the success of the project.

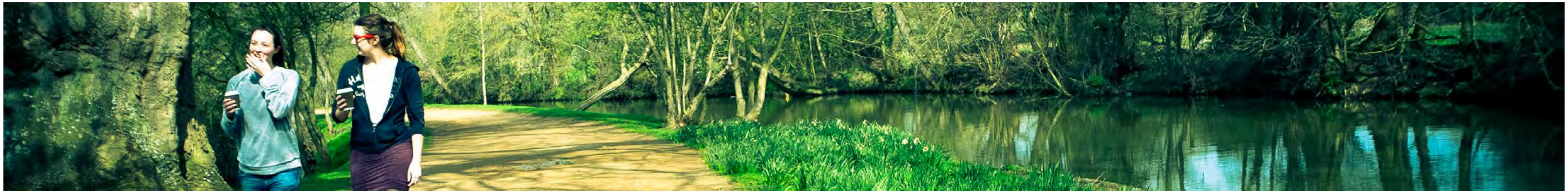
Opportunities	Issues
• Evidence of effective use of location specific taxes and TIF in other countries e.g. USA, Australia. • Could be considered investment by businesses e.g. if green infrastructure improvement leads to increased footfall.	• Persuading local businesses that investment in green space would be beneficial to them. • Some mechanisms e.g. precepts have limited application or require tax-raising powers. • Risk of excluding those who would benefit most from living near green space and increasing inequalities in health.
Key resources Tax Increment Funding Social Market Foundation – Recreating parks: securing the future of our urban green spaces Financing for a future London report	
• Can offer substantial long-term funding	• Requires skill and expertise to develop a business model and generate income. • Risk of excluding people from using green space or increasing inequalities in access.
Key resources UK Municipal Bonds Agency	

Funding mechanism	Description
ALTERNATIVE MANAGEMENT STRUCTURES	
Endowments	An endowment is a legal structure used by an organisation to manage investments (financial, property or other) for a specific purpose.
Non-profit distributing organisations (NPDOs)	The transfer of the operation, delivery and maintenance of green infrastructure from a local authority to an NDPO; this can include ownership of these spaces. NPDOs can be: unincorporated charitable trusts; charitable incorporated organisations e.g. a parks foundation; companies limited by guarantee; industrial/provident societies; community interest companies (CICs)/social enterprises.
Community asset transfers	The transfer of a piece of land or building from public ownership to community ownership. In most cases this involves a local authority transferring the ownership of an asset to a community organisation such as a Development Trust, CIC or social enterprise.
PLANNING AND DEVELOPMENT OPPORTUNITIES	
Property assets and investment portfolios	Property assets are property e.g. land, buildings, with monetary value. 'Passive' ownership of property assets in an investment portfolio assumes that they will earn a return or grow in value over time. Investment can be strategic i.e. buying with long-term aims, or tactical, active buying and selling for short-term gain.
Private sector investment models	Funding from the private sector to support the development/ maintenance of green space or provision of activities within spaces e.g through land sales, corporate social responsibility, or levies and contributions after new development, including Section 106/ Community Infrastructure Levy (CIL).
Land sales	Selling land for development by private developers to raise funds for creating green infrastructure or its maintenance e.g. through investment of funds in investment portfolios.
Section 106 Planning Gain/CIL	Legal agreement between a planning authority and a developer, or linked to a specific project or development, ensuring that certain extra works or procedures e.g. creation of green space, take place and/or are maintained in the future; essentially a levy.
ECOSYSTEM DEVELOPMENT/PAYMENT FOR ECOSYSTEM SERVICES	
Renewable energy tariffs	Renewable energy sources in green space, such as wind turbines or ground source heat pumps, can be used to generate or save income. This might be through selling energy to nearby buildings, electric car charging points, or using the energy in green space facilities such as cafes to reduce costs.
Utility and rights-of-way leasing	Payment/service charges for infrastructure/equipment in green space e.g. for electricity from residential dwellings or commercial properties.
Offsetting	• Carbon credits: buying and selling greenhouse gas emission allowances to reduce an organisation's environmental impact. • Ecological: market-based conservation tool that measures negative impacts on biodiversity, replacing the loss through environmental improvements, usually nearby.

Opportunities	Issues
• Land ownership can remain with the local authority. • Access to new funding sources. • Management boards can bring together skills and expertise. • Opportunities for long-term and strategic thinking.	• Limited oversight by local authority. • Lack of control over some aspects of green infrastructure e.g. if local authority retains ownership. • May be harder to work strategically/in partnership with delivery of other services.
Key resources Creating a Trust for Newcastle's Parks & Allotments Community Assets and Ownership	
• Land sales can provide revenue generating opportunities, with reinvestment supporting maintenance of other green space. • Investment offers long-term funding for maintenance of green infrastructure.	• Land sales unlikely to be permitted in many areas. • Community opposition either to land sales or fees as a result of Section 106/CIL. • Section 106/CIL may create green spaces which are difficult to fund in perpetuity e.g. maintenance.
Key resources Community Infrastructure Levy – An Overview Milton Keynes Parks Trust	
• Cost reduction e.g. in energy costs of green space facilities. • Income generation e.g. through electric vehicle charging. • Contribution to reducing carbon emissions and climate resilience.	• Producing a viable case for investment e.g. there have been reductions in public subsidies for renewable energy. • Cost of initial investment, from identifying sites with greatest potential to installing infrastructure. • Some e.g. offsetting are usually a one-off payment and may require national markets and regulatory frameworks.

Funding mechanism	Description
Water management	Funding for water management can be used to invest in green space e.g. flood risk reduction through Sustainable Urban Drainage systems (SUDs).
CHARITABLE GIVING AND VOLUNTARY SECTOR INVOLVEMENT	
Subscription schemes	Voluntary payment of a regular, annual membership by the public. This may confer some benefits e.g. priority access to park events but is generally in addition to the space being free and open to use.
Investment crowd funding	Requesting donations from the public, either one-off or regularly (as with charities), often to fund a specific project; whether an improvement to the space or an activity.
Donations and philanthropic partnerships	Funding from e.g. charitable trusts.
Community/volunteer groups	Management/maintenance of green space, or activities within it, by volunteers e.g. Friends of groups, either with or without coordination or partnership with the local authority/green space owner.
Corporate volunteering	Volunteer groups from local businesses or organisations, often as part of corporate social responsibility.
MULTI-AGENCY OPPORTUNITIES	
Grant funding	Funding obtained by applying to organisations such as the Heritage Lottery Fund or European Regional Development Fund, usually for specific projects e.g. green space regeneration or social prescribing schemes (see case study below).
Innovative use of public budgets	Funding from public health e.g. through Health and Wellbeing Boards or clinical commissioning groups CCGs, typically for activities such as social prescribing schemes (see case study below) within green space. Other possibilities include police budgets, as well-maintained and used green infrastructure can reduce crime, and education.
Shared-use agreements	Fees/financial contributions towards maintenance in return for use of the space e.g. by schools for sports.
Special designations	• Conservation: areas for the conservation and protection of natural resources e.g Areas of Outstanding Natural Beauty (AONBs). • Historic structures: registering green spaces or structures within them on the Historic England register.

Opportunities	Issues
Key resources Greenspace Scotland – ParkPower POSTNOTE – Biodiversity Offsetting UK Government Guidance – Biodiversity Offsetting ForestCarbon – Carbon Credits and Offsetting	
• Donations can be effective in funding specific projects e.g. regeneration. • Community involvement promotes a sense of ownership which can contribute to long term sustainability of green infrastructure.	• Unpredictable and location-specific. • Requests for donations may be off-putting for some visitors. • Require resources e.g. infrastructure to take donations, a volunteer coordinator to organise activities. • Reliant on motivated individuals. • Community groups think locally, making strategic approaches to management difficult. • Volunteers often unwilling to perform tasks seen as council responsibilities.
Key resources Nesta Rethinking Parks – Heeley People's Park CABE SPACE - Helping community groups to improve public spaces	
• Opportunities to create large change e.g. through regeneration or infrastructure development. • Shared-use and special designations can allow access to alternative funding sources.	• Funding is often for specific short-term uses and rarely funds core capacity. • Budgets are limited in other sectors too. • Challenging to access: requires commitment of time, detailed applications, may need co-funding. • The evidence base to justify and support these activities is growing but still has limitations e.g. difficult to demonstrate return on investment.
Key resources Heritage Lottery Fund European Regional Development Fund (Environmental) designated areas (Historic) conservation areas	



Case studies

The following case studies are examples of the successful use of alternative funding mechanisms for green spaces. Where there are specific routes to access or engage with these funding sources, this has been noted in the relevant case study.

Creating robust and sustainable future funding models for investing in green space for health outcomes will involve adopting different mechanisms, for different purposes, at different scales. Diversifying income streams, or blended finance models, have been recognised as essential to ensuring long-term financial sustainability, and case studies which use multiple funding mechanisms have been highlighted below. However, the development of sustainable funding models that meet the needs of different stakeholder groups, and can operate at scale, will require further thinking and discussion amongst those working in this area, to inspire innovation that informs and strengthens policy and practice.

Why not join the discussion on our Forum, and review our alternative funding mechanism Q&A webinar, on the SWEEP Investing in Nature Hub at www.sweep.ac.uk/healthwellbeing.

*(*Indicates where multiple funding mechanisms have been used.)*

Social impact bonds (SIBs)

SIBs have been used for around 10 years and tend to target complex social problems such as social prescribing.

How do SIBs work?

Usually there are four parties involved in a SIB:

- Commissioners, either central or local government bodies, responsible for the provision of public services.
- Service providers, who are responsible for implementing the commissioned public service. They are often non-profit organisations.
- (External) social investors, who cover the upfront running costs of the commissioned public service.
- Intermediaries, such as investment managers, who may be involved in securing contracts as well as public service development or delivery.

Commissioners commit to repay investors their initial investment and a return, if pre-defined target outcomes are achieved, so repayment depends on the success of the project.

Case study: Healthier Devon

Location: Devon
Partners: Big Lottery Better Outcomes Fund/Devon County Council (commissioner), Westbank (provider), Bridges Social Impact Fund (investors)
Funding: £657,068 (Big Lottery Commissioning Better Outcomes), £117, 000 (Devon County Council)

Aims

Healthier Devon was commissioned by Devon County Council, with support from Bridges and Big Lottery Fund, and is being delivered by the charity Westbank. It provides two years of support for those in Devon most at risk of developing Type 2 diabetes. People are referred by their GP surgery through the Devon Referral Support Service. The programme involves lifestyle changes around diet and physical activity.

Outcomes

Devon County Council will only make payments to the investors if individuals enrolled on the programme show a sustained drop in their weight, their waist circumference and their HbA1c (blood sugars) reading.

How to access

SIBs are issued by the public sector (although the private sector can access them in theory). Further support and information is available from organisations such as Social Finance and the Government Outcomes Lab; there are also several central government funds e.g. the Life Chances Fund.

Key resources

- Carter, E., FitzGerald, C., Dixon, R., Economy, C., Hameed, T. and Airoldi, M. (2018) *Building the tools for public services to secure better outcomes: Collaboration, Prevention, Innovation.*
- Davies, R. (2014) *Social impact bonds. European Parliamentary Research Service briefing*.

Working with corporate partners

A range of mechanisms can be used to work with corporate partners to manage and improve green space. Corporate social responsibility can include both donations (monetary or direct contributions e.g. to develop or use spaces within parks) and volunteers from local businesses, whilst business improvement districts can levy funds to develop green space from local businesses.

Corporate social responsibility

Corporate Social Responsibility (CSR) refers to the efforts made by a company to improve society and contribute towards sustainable development.

*Case study: The Conservation Volunteers (TCV)

Location: UK
Partners: TCV and businesses
Funding: Businesses

Aims

Corporate partnerships to improve the environment, motivate workforces, and enable businesses to meet CSR aims.

Outcomes

TCV offers package and bespoke corporate partnerships. Successful examples include:

- I Dig Trees – a national tree planting programme with OVO Energy, who fund the trees, with TCV carrying out planting via volunteer programmes. This has distributed and planted over 1 million new native trees across the UK since 2015.
- Opportunities to sponsor Green Gyms or outdoor spaces run by TCV.
- Corporate volunteer days - 3,500 employees from 20 employers in 2013/14, from companies including RBS, Mondelēz, PwC, Asda, HSBC, CISCO, Intu and Blackstone Group.

Every £1.00 spent with TCV on Corporate Community Partnership activities produced a Social Return on Investment of almost £4.00, with a positive impact on employee wellbeing and business reputation.

Key resources

- NEF Consulting and TCV (2015) *TCV's impact: Organisational Social Return on Investment summary findings.*

Business Improvement Districts (BIDs)

Businesses in a defined area vote on a business plan in a ballot to decide whether to implement a BID. If successful, they pay an additional business levy.

Only businesses with a rateable value above £150,000 pay the BID levy; charities are exempt. The levy is used only for the specific projects set out in the business plan. BIDs are governed by a voluntary board of business levy payers representing all sectors in the area. Observers also attend to represent public sector service providers and local charities. The board leads and guides the work of the BID and is supported by the executive team which implements, delivers and measures mandated programmes and projects.

*Case study: Victoria BID

Location: London
Partners: Local businesses, Natural England, Greater London Authority and Westminster City Council
Funding: £2 million per year

Aims

One theme of the Victoria BID is 'Public realm and greening', with one aim being enhancing green infrastructure in Victoria to:

- Promote use of these areas and create a sense of place, improving workforce satisfaction.
- Provide environmental benefits such as a reduction in flooding and climate and temperature adaptation.
- Increase land value.

Outcomes

Victoria BID was started in 2010, in response to a report that the area was in a critical flood zone. It was renewed in 2015 and has recently been renewed for a third 5-year term, with a levy of £2.5 million per year for 5 years.

In terms of green infrastructure:

- An initial green infrastructure audit showed that existing green infrastructure diverts 112,400m^3 of storm water run-off from the local sewer system every year, resulting in between £20,638–£29,006 of annual CO^2 and energy savings. Further development could reduce peak temp by 5.1^{o}c and reduce flooding further.
- A series of seminars were run on green roofs, SuDS and biodiversity management, they were popular and engaged businesses, as they understood the strategy of the BID, meaning they were more willing to contribute.
- The green infrastructure audit encouraged BID members to invest in urban greening as part of their long-term regeneration strategies.
- Led to Victoria BID being awarded a £15,000 grant from a Natural England fund administered by the Cross River Partnership to produce a guide aimed at all BIDs in 2013.

How to access

BIDs can be set up by local authorities, business rate payers or people/companies who have an interest in the land in the area. There is a £500,000 loan fund available from the government to help communities with initial start-up costs.

Renewable energy

Renewable energy could help green spaces become more financially sustainable by:

- creating new sources of income (particularly long term)
- reducing operating costs.

It also contributes to a greener, more sustainable economy, helping reduce carbon emissions and providing an example of the transition to net zero for individuals and organisations. Urban green spaces are ideal because they have the resources (land, water, wind) to generate energy and the location (they are situated in areas with high energy demand).

Case study: Powering Parks

Location: Hackney
Partners: 10:10 Climate Action (charity using public engagement and participation to create solutions to climate change), Hackney Council (manages all of the greenspaces and will play a key role in delivering the demonstration project), Scene Consulting (experienced energy consultants focusing on community scale solutions, responsible for system design)
Funding: Nesta Rethinking Parks

Aims

Heat pumps collect ambient heat stored in the ground, bodies of water, or the air and concentrate it so it can then be pumped into buildings. The aims of Powering Parks were to:

- Install heat pumps in a Hackney Park and use these to supply energy to nearby buildings
- Demonstrate the feasibility of the use of heat pumps
- Provide resources for others to use to do this.

Outcomes

The project assessed the opportunity to use ground source heat pumps across the whole of Hackney's parks and greenspaces and matched these spaces to nearby council or third party buildings.

A suitable site, Abney Park Cemetery, was selected and a business case was developed for consideration by the council.

As well as building and installing the infrastructure, there was a focus on engaging local people from the start to make sure they were on board.

Powering Parks created a replication package for other parks managers - including an online early-stage feasibility tool – and are running dissemination events for local authorities and others to attend to find out more.

Key resources

- Nesta (2020) *Harnessing renewable energy in parks*. London: Nesta.
- Waters and Robinson (2019) *Powering Parks*.

Payment for ecosystem services (PES)

Ecosystem services are the benefits to society provided by the natural environment. The concept of PES involves creating a market for these services, with voluntary market-like transactions between buyers (e.g. businesses, recreational visitors, water companies) and sellers (e.g. landowners) of ecosystem services. This might involve asking the beneficiaries of services to pay for them and providing incentives to manage land for their provision. In the case of urban green infrastructure, beneficiaries may include local residents, local businesses, developers, and local authorities.

PES can vary in scale from international to catchment or local. There are three types of scheme:

- public payment schemes - the government pays land or resource managers to enhance ecosystem services on behalf of the public;
- private payment schemes - self-organised private deals in which beneficiaries of ecosystem services create a contract directly with service providers;
- public-private payment schemes - these draw on both government and private funds to pay land or other resource managers for the delivery of ecosystem services.

The most successful so far have been around carbon and water management, where pathways and actions are clear. PES includes offsetting, where organisations which are creating an environmental impact e.g. through their carbon emissions, or by building on green field sites, can pay to improve the environment elsewhere. Examples include habitat restoration schemes, sustainable urban drainage systems, or projects to remove carbon from the environment such as tree planting or peat land restoration.

The DEFRA PES pilot scheme created a process for PES development: (i) identify a saleable ecosystem service and prospective buyers and sellers; (ii) establish PES scheme principles and resolve technical issues; (iii) negotiate and implement agreements; (iv) monitor, evaluate and review implementation; and (v) consider opportunities for multiple-benefit PES.

Case study 1: River Lyd NatureBid

Location: Devon
Partners: Westcountry Rivers Trust, Environment Agency, Sylva Foundation, Channel Payments for Ecosystem Services (CPES) Interreg EU-funded project
Funding: Tamar Water Stewardship Business Board

Aims

Farmers and landowners in the River Lyd catchment submitted bids to an online auction to obtain grant funding for projects aimed at improving water quality. Examples of projects include woodland planting, aeration or sub-soiling of grassland, cover crops for arable areas, watercourse fencing, field buffer strips, installing ponds or wetland features. Whilst aimed at water quality improvement, they offer additional benefits such as flood risk reduction and carbon sequestration. This project began in 2017 and will run until 2021.

Outcomes

The Water Stewardship Business Board is made up of organisations who have direct or indirect interests in the local area due to their operations and supply chains, including ABP, Kepak, Premier Foods, Saputo Dairy UK, Arla, and South West Water. It contributes to improving the longer-term resilience of river catchments in the area and contributed the funds for the auction.

Bids were assessed based on their effectiveness in improving water quality and their cost-effectiveness, to ensure value for money. Demand outstripped supply, indicating that farmers and landowners are interested in implementing measures for environmental protection if they support the farm business, and that a clear and simple application process encourages greater uptake.

Data from a pilot targeted auction (funded as part of the government PES pilot scheme) found that the method significantly increased the value for money with which funds can be allocated to projects (environmental improvements per £). These were estimated at between 20-40% greater value for money compared to a fixed-price, advisor-led scheme.

Case study 2: Nurture Lakeland

Location: Lake District
Partners: Nurture Lakeland
Funding: Visitors to the area

Aims

Nurture Lakeland trialled a Visitor Payback Scheme as a part of a pilot PES in the Bassenthwaite catchment in 2009. The scheme took an integrated approach to managing the area for multiple outcomes as the area is an important cultural landscape (for scenery and outdoor recreation) and has high visitor numbers (over 2.5 million per year).

Tourists were asked to contribute to landscape management through a small donation. Business could join the scheme and collect donations if they had a customer base of over 1000 per year. They then chose one of three projects to donate the money to: 'Fix the Fells' which focuses on the protection and restoration of footpaths; 'The Osprey Project' which supports the re-colonisation of the area by this rare species; and 'Love your Lakes' which is working to improve Lakeland water quality. All are run by existing charitable organisations.

Businesses collect money from their customers using either an opt-out system via the bookings systems; donation envelopes; or sponsored products. Nurture Lakeland then distributes money to the charitable organisations. Payment is conditional on receiving annual monitoring data and the submission of a work plan, costings, and other background information.

Outcomes

The scheme is one of the few existing PES mechanisms that allow tourists who benefit from the natural environment to directly support it. Nurture Lakeland has raised almost £2million in donations over an 18-year period through the scheme. It created a sense of ownership of the landscape among businesses and all but one continued with the scheme.

This type of scheme could be set up anywhere with a significant tourism industry. It does involve some time: Nurture Lakeland found initial funding needs to be in place to set up infrastructure e.g. donation websites for businesses which takes around 3-6 months, with significant fundraising taking 1 to 2 years.

Key resources

- DEFRA (2013) *Payments for ecosystem services: a best practice guide. Annex – Case studies.*

Social prescribing

Social prescribing schemes allow medical professionals to refer people to non-clinical activities which could support their health and wellbeing. In green infrastructure, these might include activities such as horticultural therapy or walking groups. A recent report on social prescribing identified the lack of movement of funding between sectors as being a key problem in its provision. Current sources of funding for general social prescribing come from:

No funding (10%)	Local Authority (19%)	Clinical Commissioning Group (26%)
Lottery (13%)	Primary Care Networks (9%)	VCSE (7%)
NHS (3%)	Privately funded (3%)	Other (12%)

Projects cannot rely on funding from the health service. The report recommended that any organisations that take referrals from social prescribing link workers should receive funding.

Case study: Natural Health Service

Natural Health Service

Location: Merseyside and Cheshire
Partners: The Mersey Forest, The Community Forest Trust, landowners, delivery organisations, policy and academic partners and strategic partners
Funding: National Lottery Community Fund

Aims
The Natural Health Service began in September 2013, with £400,000 of funding. It offers a single point of access to a range of well-developed and evidence-based services in natural green spaces. It coordinates activities and is also involved with delivery of some nature-based interventions.

Project partners lead on delivering programmes as a whole rather than by number of participants. Programmes last six to eight weeks and include nature walking, horticultural therapy, forest school, green volunteering, green gym and mindful contact with nature. They are open to everyone but intended mostly for participants with mild to moderate mental health problems, who are signposted to other services as required following participation. They can self-refer or be referred by any qualified health provider (primary and secondary).

Outcomes
Evaluation of Nature4Health, a Natural Health Service programme, found that it led to a significant improvement in mental wellbeing (12 points on the Warwick-Edinburgh Mental Wellbeing Scale, with 3-8 points being considered significant) for participants in its first year. Physical activity also increased as a result of the programme.

A Social Return on Investment (2016) study into an expanded Natural Health Service, working with around 6,000 people a year who are at high risk, predicted a return on investment of £6.75 social return for every £1.00 invested in the service.

How to access
Most social prescribing is still project-funded e.g. Big Lottery, though there is some central funding and use of public health budgets. The National Academy of Social Prescribing is a source of further information and support.

Key resources
- Cole, A., Jones, D., Jopling, K. (2020) *Rolling out social prescribing*. London: National Voices.
- Natural England (2017) *Good practice in social prescribing for mental health: the role of nature-based interventions*.
- The Conservation Volunteers (2020) *Enabling the potential of social prescribing.*

General Resources

This section contains research and reports, additional to those linked to specific funding mechanisms above, which were reviewed to produce this report. These are general resources with further detail on a range of funding mechanisms for green space outlined in this report.

- CABE SPACE *Is the grass greener?*
- CABE SPACE *Does money grow on trees?*
- Communities and Local Government Committee *The Future of public parks*
- Dobson, J., Harris, C., Eadson, W., and Gore, T. (2019). *Space to thrive: A rapid evidence review of the benefits of parks and green spaces for people and communities*. The National Lottery Heritage Fund and The National Lottery Community Fund, London.
- Good Parks for London 2020 *Parks and the Pandemic*
- *Greater Manchester Natural Capital Investment Plan*
- Grow Green *Approaches to financing nature-based solutions in cities*
- *London Green Spaces Commission report*
- Mell, I. (2017) *Establishing the costs of poor green space management: mistrust, financing & future development options in the UK.* People, Policy and Place, 12, 137-157.
- Neal, P. (2013) *Rethinking Parks: exploring new business models for parks in the 21st century.* London: Nesta.
- Nesta (2016) *Learning to rethink parks.* London: Nesta.
- Nesta (2018) *Meet the Rethinking Parks innovators: Eight parks projects developing promising and innovative operating models.* London: Nesta.
- PERFECT project *Investment finance for green infrastructure*
- Uncertain Prospects *Public Parks in the new age of austerity*
- Whitten, M. (2019) *Blame it on austerity? Examining the impetus behind London's changing green space governance.* People, Place and Policy, 12, 204-224.

De Bell, S., Abrahams, R., Lovell, R.& Wheeler, B. (2021) *Alternative funding mechanisms for green space.* SWEEP report, produced as part of the Investing in Nature for Health project.

SWEEP is a partnership between the University of Exeter, the University of Plymouth and Plymouth Marine Laboratory.

Funded by NERC, it brings together experts and stakeholders to solve key challenges faced by those working with our natural resources.

Economic and Non-economic Measures and Tools

Evaluating the health and wellbeing benefits of nature based health interventions

This Resource

Who should read this?

This information is relevant for individuals and organisations who are planning or implementing interventions in green and blue spaces, whether they are from the environmental management, urban planning and public health sectors or voluntary sector organisations. It will also be of interest to funders and policy makers working in this space.

Why this resource matters

For centuries, people have found solace and respite through nature. Now, increasing evidence (Wheeler et al. 2020) shows that the benefits of spending time in nature extend beyond 'feeling good' to longer term improvements in our physical and mental health, and wellbeing. This has resulted in a growing number of environmental projects aimed at improving public health through a variety of interventions. These include activities that increase the extent and access to green and blue spaces, enhance the quality of these spaces (both ecologically and the physical infrastructure they provide) and the programmes of activities that aim to enhance their use.

At a time of rapidly escalating mental and physical health concerns and costs, coupled with an ever increasingly competitive funding environment, there is an urgent need to develop more robust business cases that ensure continued and appropriate investment into this area. In order to do this, practitioners and funders need to better understand, and be able to communicate about, the effectiveness of nature-based health projects. To do this, they need access to the latest evidence around evaluation metrics and approaches suitable for evaluating the impacts and outcomes of programmes that invest in the environment for health.

What is this resource about – and what is its value?

This resource presents a list of some of the economic and non-economic measures and tools most commonly used to measure health and wellbeing outcomes. It draws on some of the latest research evidence, as well as literature that examines applied case studies of investments in the environment for health.

The evidence contained in this resource has been derived both from a database of evidence created as part of this SWEEP Investing in nature for health project, as well as from wider publically available evidence. In 2020, the team carried out a literature review across two academic databases; Web of Science and SCOPUS. 400+ papers were identified that considered nature-based health interventions, explicitly connecting natural resources with health outcomes, both from and outside the UK. These included reviews, concept papers and empirical studies, to which approximately 100 grey literature items were added to include contemporary programmes, projects and research findings.

Benefits to you:

By bringing this information together in one place, we aim to ease your access to the range of measures and tools that currently exist for evaluating the success of nature-based interventions and programmes. These include both broad, non-economic measures as well as those that have been converted to economic values. We hope this provides you with inspiration for your own work - replicating successes, avoiding pit falls, extending your contacts and evidence-base, and supporting you to –

- Communicate with others about known pathways through which green and blue space interventions may benefit human health
- Make a more informed choice as to which measures and tools might be most appropriate to evaluate the success of your own programmes and interventions in terms of the social, environmental and economic outputs, outcomes and impacts they deliver
- Use these to show how investment in nature-based health interventions can deliver on multiple priority aims and outcomes and can deliver an economic case for further investment

Good to note ...

Is this a comprehensive list of metrics and tools?

Whilst useful, this is an active, non-exhaustive list. Please contact the author if you have further measures and tools to add.

Measuring health outcomes

Whilst improved health and wellbeing may be the ultimate aim of these projects, it is not always appropriate, or achievable, to measure health outcomes directly. This is due to a variety of factors such as the intangible nature of some health outcomes, ethical issues, and the long timeframes often involved in delivering interventions that lead to health outcomes. For this reason, alternative measures may need to be considered, such as the use of secondary, intermediate outcomes or proxies, where pathways between components of the intervention and health are known. For example, between increased levels of physical activity and more immediate impacts to mental health (Hunter et al. 2017).

Other useful SWEEP resources

The SWEEP Investing in Nature for Health team has delivered a suite of resources, some of which provide more detailed information on frameworks suitable for evaluating and communicating the success of programmes that invest in nature for health. Please see:

- Understanding environmental investment for health in the South West – a resource exploring dynamic mapping case studies
- Evaluating interventions in green space: Derriford Community Park, Plymouth, Devon – using causal loop diagrams
- 5 capitals model approach

Evidence-based measures for evaluating the success of nature based health interventions

The tables below display a non-exhaustive list of both economic and non-economic metrics and tools used to measure various relationships between human health and wellbeing, and green/blue space interventions.

The tables provide a brief description, or definition, of each measure, the main methods used to deploy the measures, and links to related resources and case studies of applications.

The need for further research

The relative paucity of evidence that attempts to derive economic values from measures of natural environment based health benefits is a point of note in itself. This would suggest that further research is needed to secure more standardised measures that offer practical solutions for providers of health based environmental programmes and interventions.

Most common and useful units of measure

The Quality Adjusted Life Year (QALY) is the most commonly used unit of measure for conversion to economic value across the case studies presented here. It therefore represents the closest thing to a standard measure of health benefits. This measure is often used as it can readily be translated to an economic value, although it should be noted, that values derived from, or attributable to, any one QALY can vary.

In view of the benefits and common use of QALYs, it is worth considering, when making decisions on which scales or metric combinations to use, how easily these can be converted to QALYs. Incorporating anticipated economic values of health and wellbeing from such measures into cost-benefit analyses, along with other direct costs, will help to strengthen your proposals and persuade service providers or funders to invest.

Social Return On Investments (SROIs) also provide an effective valuation option, particularly where it is useful to compare values of investments, or particular services and/or interventions.

Case studies

A range of case studies have been included in the tables below that illustrate how economic and non-economic measures and tools have been used to evaluate the health and wellbeing benefits of nature-based health interventions.

Table 1 Case studies here link to the study paper and are referenced at the end of the document.

Table 2 Case studies here link to a separate SWEEP supporting document. Based on feedback from our partners, this provides an easy to use overview of the key points of interest for each case including, a brief summary; name of the measure used; method of application; results; effort required to obtain measure and potential users of the metrics.

Top resource

Although this document signposts to a number of resources, one that stands out for breadth and depth of indicators related to nature-based solutions (NBS) is the European Commission's **Evaluating the impact of nature-based solutions : appendix of methods** (https://data.europa.eu/doi/10.2777/11361). This handbook offers a compilation of indicators and methodologies to assess impacts of nature-based solutions across 12 societal challenge areas. Contributions were drawn from experts from 18 EU Horizon2020 projects and other European programmes.

Table 1 NON-ECONOMIC Health and wellbeing measures and approaches

PHYSICAL HEALTH	Method and description	Resources	Case studies
Visit frequency/time in nature	**Survey** Spending time in nature is associated with mental well-being (White et al. 2019). Nationally representative surveys such as the Monitor of Engagement with the Natural Environment (MENE) survey ask visitors to self-report how often they visit nature and the duration of their last visit to nature.	MENE technical report, including survey questions	White et al. (2019) Spending at least 120 minutes a week in nature is associated with good health and wellbeing
Evaluation of site quality and experience	**Use of various measures** To assess the quality of a green/blue space, and user experience of the space. May typically be done via longitudinal methods i.e. before and after a change to the site (environmental intervention).		
i.e. WIAT (Woods in and around Towns) Environmental Audit Tool	**Combines an environmental audit and survey questionnaire** To assess woodland site interventions. Inc. measures of wellbeing, physical health, perceived stress, nature connectedness, general health, social capital, and perceptions of environment.	Protocol for WIAT questionnaire and audit tool	Forestry Commission Glasgow Case Study 2010 Report: overview of WIAT
System for Observing Parks and Recreation in Communities (SOPARC)	**Observation** A validated tool for assessing activities within parks, involving observation of users' physical activity levels, type of use, and demographics e.g. gender. It also collects information on the area's characteristics e.g. accessibility.	SOPARC App (online app no longer available but guides are) SOPARC User Guides	Vert et al. 2019 Evaluation of an urban riverside regeneration project which aimed to improve access for pedestrians and cyclists.
SOPARNA	**Observation** An adaptation of SOPARC for measuring recreation- and physical activity-related behaviour in natural open spaces. Measures level of physical activity in relation to specific environmental features.	SOPARNA description and procedures manual	Case studies provided within the Supporting Document - Economic and Non-economic Measures and Tools
World Health Organisation Health Economic Assessment Tool (HEAT)	**Observation** HEAT calculates the reduction in mortality, and value of this reduction, resulting from walking and cycling. It can assess current levels and changes over time, as well as evaluating projects. Application is to populations, not individuals. Data is needed on the size of the population and the amount of time people walk or cycle in the space being assessed.	HEAT assessment tool and guide WHO HEAT Methods and User Guide	Cavil et al. 2014 Assessment of the value of walking on the coast path.
International Physical Activity Questionnaire (IPAQ) *See also SOPARC above*	**Survey** This measures health-related physical activity in populations. Long and short versions are available. Can be self-administered.	IPAQ questionnaire and scoring guide	Saran et al. 2018 Use of IPAQ for monitoring physical activity of patients with cardiovascular diseases.

MENTAL HEALTH	Method and description	Resources	Case studies
The 5-item World Health Organization Well-Being Index (WHO-5)	**Survey** A measure of current wellbeing, consisting of five statements which are rated on a scale.		
Office for National Statistics personal wellbeing scale (ONS-4)	**Survey** As with the WHO-5, the ONS-4 are four statements that are rated on a scale. They measure three aspects of wellbeing: life satisfaction, feeling that life is worthwhile, and wellbeing in the moment (feelings of happiness and anxiety).	ONS Personal well-being user guidance	NEAR Health toolkit (p57 and Appendices) – a resource to connect nature with health & wellbeing.
Warwick-Edinburgh Mental Wellbeing Scale (WEMWBS)	**Survey** A measure of mental wellbeing with two scales, a 14-item and shorter 7-item scale (SWEMWBS). Applied widely and in various settings. Good for evaluating interventions/projects.	WEMWBS Overview and guide to use	Wetlands for Wellbeing – a Wildfowl & Wetlands Trust site pilot study.
Other relevant scales e.g. Perceived Stress Scale, Perceived Restorativeness Scale	**Survey** The survey includes the Perceived Stress Scale questionnaire, which includes 4 items on the amount of time in the last month that the participant felt a certain way. The answers are on a scale from 0 (never) to 4 (very often). Repeated before and after the implementations of NBS in order to observe a potential change in mental health status.	NBS Appendix, section 21	Social prescription referrals to Wellbeing Garden
Social Media	**Quantitative and qualitative analysis of social media content** Use of social media platforms to record sentiment as a measure of wellbeing.	Twitter sentiment to measure wellbeing of public park users	Berger, 2021 The Effect of a Combined Nature-based and Virtual Mindfulness Intervention on Perceived Stress in Healthcare Workers.
Connection to nature	**Survey** Nature connection is associated with health outcomes such as happiness and wellbeing as well as pro-environmental behaviours e.g. (Capaldi et al. 2014; Pritchard et al. 2019). There are several validated scales which can be used to measure nature connection e.g. Nature Connection Index (NCI); Connectedness to Nature Scale (CNS), Inclusion of Nature in Self Scale (INS)	Paper: Connectedness to Nature Scale Connectedness to Nature Scale survey questions and code Salazar et al. (2020) Nature Connection Index Salazar et al. (2020) Inclusion of Nature in Self Scale (p34-36).	Mayer & Frantz, 2004 The connectedness to nature scale: A measure of individuals' feeling in community with nature. Richardson et al. 2019 A Measure of Nature Connectedness for Children and Adults: Validation, Performance, and Insights. Richardson & McEwan 2018 30 Days Wild evaluation for Wildlife Trusts.

NEAR Health toolkit	**Survey** Incorporates several measures (ONS-4, NCI, MENE) in a before and after questionnaire to assess how blue and green nature-based activities impact on changes in various aspects of people's lives. A 5-point scale version for children was also produced.	Research 348 Toolkit: Connecting with Nature for Health and Wellbeing	NEAR Health toolkit – a resource to connect nature with health & wellbeing.
Engagement with nature	**Survey** A simple measure of nature connection which asks about activities performed e.g. watching wildlife, smelling wildflowers, listening to birdsong, taking photos of nature, using a scale of 1 (never) -4 (often).	Engagement with nature	Richardson et al. 2021 Moments, not minutes: The nature wellbeing relationship
Pro-nature Conservation Behaviour Scale	**Survey** A validated scale which measures active behaviours that support the conservation of biodiversity e.g. volunteering, litter-picking.	Pro-nature Conservation Behaviour Scale Blog: Pro-nature Conservation Behaviour Scale	Barbett et al. 2020 Measuring Actions for Nature - Development and Validation of a Pro-Nature Conservation Behaviour Scale.

SOCIAL HEALTH	**Method and description**	**Resources**	**Case studies**
Nature Prescriptions	**Green prescriptions** Such as gardening, can be used as a non-medical asset-based approach by health professionals working in the community as a way to promote health and wellbeing.	Community wellbeing	Howarth et al. 2020 An example of gardening of as a nature-based social prescription provided by the RHS Bridgewater Wellbeing Garden.
See also SOPARC	**Observation** One pathway for connecting physical health and public parks is through collective efficacy where neighbourhood parks act as a hub for social cohesion.	SOPARC App (online app no longer available but guides are) SOPARC User Guides	
See also WIAT	**Environmental audit** The protocol followed for environmental audit of a green space in this case focuses on a community-level evaluation of WIAT interventions aimed at improving woodlands so as, ultimately, to improve people's quality of life.	Protocol for WIAT questionnaire and audit tool	Forestry Commission Glasgow Case Study 2010 - Report: overview of WIAT
Sense of empowerment	**Survey** role of community gardening in advancing community empowerment.	NBS Appendix, p834	Cumbers et al. 2018 The Work of Community Gardens: Reclaiming Place for Community in the City.

Table 2 ECONOMIC Health & wellbeing measures and tools that can be used to derive economic values

These case studies all link to a separate SWEEP supporting document [add hyperlink] where they correspond directly to the same health category and case study number as shown below.

PHYSICAL HEALTH	Method and description	Resources	Case studies
Quality Adjusted Life Years (QALY)	A measure of the health benefits that combine duration and quality of life, with one QALY representing one year of life in full health.	Do you know what a QALY is, and how to calculate it?	Moseley et al. (2018) developed a quantitative physical indicator for woodland recreation that can help managers to quantify the health benefits of recreation activities undertaken in their woodlands to inform local scale planning. The authors first obtained a non-financial estimate of annual calorific expenditure (ACE) based on a quality of experience survey that consisted of a standard set of questions for participants. This was accompanied by a measure of intensity of activities in calories and METs (Metabolic Equivalence of Task) where one MET is the energy equivalent to an individual seated at rest. Finally, the METs were used to calculate QALYs to which an economic value was applied. (**Case Study 1)**
Disability Adjusted Life Years (DALYs); PREVENT model	One DALY represents the loss of the equivalent of one year of full health. DALYs are the sum of the years of life lost due to premature mortality (YLLs) and the years lived with a disability (YLDs) due to prevalent cases of a disease or health condition in a population.	What is a DALY?	Dallat et al. (2013) estimated the potential health impacts and cost-effectiveness of an urban regeneration project in Northern Ireland, the Connswater Community Greenway, offering new cycle and walk-ways and providing accessible and safe green space. (**Case Study 2)**
	PREVENT was developed in 1988 to estimate the health benefits of changes in risk factor prevalence for a population. It is based on the epidemiological effect measure 'potential impact fraction' which derives a proportional change in disease risk from a change in risk factor exposure and relative risk of that factor related to the health issue under study	Full details of the methods and theory behind the original model developed by L. Gunning-Schepers (1989).	Macro-simulation PREVENT model used to model the impact of physical activity on the incidence of several physical-related diseases. Physical activity and health data obtained from before and after Global Physical Activity Questionnaire, as well as various other secondary data sources. The model calculated the gains in life expectancy (LE) and disability-adjusted life expectancy (DALE) for intervention beneficiaries and the years lived with disability (YLD) saved by the Greenway population. Costs saved through diseases averted were calculated and summed to get total disease cost savings; health outcomes were derivedi n DALYs.

Blue Active Tool; DALYs , SOPARC	This tool provides estimates of the health impacts in terms of all-cause mortality, morbidity, and DALYs, as well as health economic assessment in terms of the value of statistical life (VSL) and direct health costs. Estimates of impacts for each type of physical activity and age group are estimated.	Bespoke spreadsheet Blue Active Tool described in journal paper at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6388232/	Vert et al. 2019 Health Benefits of Physical Activity Related to an Urban Riverside Regeneration. This aimed to quantify health and health-related economic impacts associated with physical activity in an urban riverside park in Barcelona, Spain. (**Case Studies 4 & 7)**
WHO's Health Economic Assessment Tool (HEAT); QALYs; UEA MOVES tool	HEAT is a web-based tool used to estimate the health and economic impacts of increased walking and cycling. It assesses impacts on premature mortality in an integrated manner through changes in physical activity levels. Can be used to assess the anticipated health benefits or harms of policies, strategies and projects that lead to changes in walking and cycling population levels.	HEAT assessment tool and guide WHO HEAT Methods and User Guide	Petersen (2020) provides a health and wellbeing valuation of the South West Coast Path (SWCP) based on available visitor and population data on visits to the trail. Drawing on visitor data, online survey and secondary data, the author applies the HEAT tool to calculate the reduced death rate using the statistical value of a life; QALYs to calculate the value of the additional years lived as a result of improvements in health and reduced incidence of disease, and MOVES to calculate the savings in health care costs based on the reduced incidence of disease among walkers compared to non-walkers, converting this into savings to the NHS. (**Case Study 5**) Cavil et al. (2014) uses the World Health Organisation Health Economic Assessment Tool (HEAT) to conduct an economic assessment of the health benefits arising from people walking regularly on the Wales Coast Path. Used data from counters on the path, and user surveys. (**Case Study 6)**

MENTAL HEALTH	Method and description	Resources	Case studies
Personal Wellbeing Index (PWI); QALYs	A self-administered scale that measures satisfaction with the following life domains: standard of living, health, life achievement, personal relationships, personal safety, community connectedness and future security.	Protocol for the Personal Wellbeing Index for an Adult	Buckley et al. (2019) evaluate methods to calculate the economic value of protected areas derived from the improved mental health of visitors, and compare these to values arising from ecosystem services, biodiversity prospecting, and tourism. **(Case Study 8)** The PWI was measured for visitors to Australian national parks and compared to national statistics to derive an estimate per capita differential (ΔPWI). Published estimates of $ per QALY were used to convert ΔPWI to $/visitor. Scaled up to provide a total annual value for Australia.
Wellbeing Valuation approach via Mental Health Social Value Calculator	A software calculator that can help organisations to monitor the impact of their activities on mental health. Incorporates WEMWBS and wellbeing evaluation.	The Mental Health Social Value Calculator can be downloaded at UK Social Value Bank | HACT	Maund et al. (2019) conducted a pilot study of a 6-week nature-based health intervention aiming to engage individuals with wetland nature for the treatment of anxiety and/or depression. **(Case Study 9)** Questionnaires were applied to the programme participants and included a range of mental health indicators. The Mental Health Social Value Calculator was used to apply the Wellbeing Valuation approach to the WEMWBS data to obtain a monetary value of the intervention.

SOCIAL COHESION	Method and description	Resources	Case studies
CONNECT social prescribing service, carbon footprint	The CONNECT project was operated by Carlisle Eden Mind from 2011-2014 and involved non-healthcare staff referring patients to local environmental projects.	Information about the CONNECT project	Maughan et al. (2016) assessed the effects of a social prescribing service development on healthcare use and the subsequent economic and environmental costs. **(Case Study 11)** Outcome measures from the CONNECT project intervention included no. of GP appointments, prescriptions of psychotropic medications and the no. of secondary care referrals. Financial impacts were calculated for each outcome using national averages or accepted conversion factors.
Social Return on Investment value	Quantifies the value of work an organisation provides for the communities they work with. The tool provides guidance for allocating a financial value to a wide range of outcomes even if not originally measured in financial terms.	Guidance on Starting Out on SROI A Guide to SROI	Bagnall et al. (2019) undertook a SROI analysis of the findings of a report in 2017 that investigated the changes in the attitudes, perceptions and mental wellbeing of Wildlife Trust volunteers taking part in nature conservation volunteering activities over a 12 week period. Financial proxies for social values (WEMWBS, good overall health, nature relatedness, level of physical activity, volunteer time) were found using the Global Value Exchange Tool, the Social Value Calculator, and a spreadsheet resource from the Greenspace Scotland SROI. **(Case Study 12)**

WHOLE VALUATION OF AN INTERVENTION	Method and description	Resources	Case studies
Cost-consequences analysis (CCA) and exploratory cost-utility analysis (CUA)	CCA is an economic appraisal that uses a cost-benefit analysis framework, but does not try to measure all of the costs and benefits in money terms. CUA is a form of cost effectiveness analysis in which benefits are measured in terms of changes in QALYs	Techniques of economic appraisal	Thompson et al. (2019) evaluated whether the implementation of a programme designed to improve the quality of, and access to, local woodlands in deprived communities in Scotland, UK, was associated with lower perceived stress or other health-related outcomes. They assessed physical (footpath construction and maintenances, new signage and entrance features) and social (programme of community-level activities and events, e.g., guided walks, 'family fun' days, 'scavenger hunts', and woodland based classes for school-children) interventions undertaken over a period of eight months, as part of the Forestry Commission Scotland's Woods In and Around Towns (WIAT) programme. Non-economic measures included Perceived Stress Scale, quality of life EQ-5D, the International Physical Activity Questionnaire, INS, QALYs and social cohesion based on 3 items from the English Citizenship Survey. **(Case Study 13)** CCA was used to identify cost related to the primary and secondary outcomes while CUA was applied to the EQ-5D responses for the WIAT interventions.

BROAD SCALE REVIEW	Method and description	Resources	Case studies
Scoping synthesis	Review of various applications of physical and mental health measures to assess cost effectiveness of nature-based interventions.		Lovell et al. (2019) completed a scoping synthesis which sought to contribute to the process of identifying 'what works' in natural environment-based health interventions. They reviewed various applications of mental health measures to assess cost-effectiveness of NBI's. **(Case Studies 10, 14 & 15)**

References

Association for Consultancy and Engineering (2020). *Measures for successful outcomes: the five capitals approach - A discussion paper.* https://www.acenet.co.uk/media/5151/ace-five-capitals-report-2020.pdf

Barbett, L., Stupple, E., Sweet, M., Schofield, M., & Richardson, M. (2020). Measuring Actions for Nature—Development and Validation of a Pro-Nature Conservation Behaviour Scale. *Sustainability*, *12*(12), 4885. MDPI AG. Retrieved from http://dx.doi.org/10.3390/su12124885

Capaldi, C. A., Dopko, R. L., Zelenski, J. M. (2014) The relationship between nature connectedness and happiness: a meta-analysis. *Frontiers in Psychology*, 5, 976. https://doi.org/10.3389/fpsyg.2014.00976

Cavil, N., H. Rutter, and R. Gower (2014) *Economic assessment of the health benefits of walking on the Wales Coast Path*. https://walescoastpathcdn-01.azureedge.net/media/1321/economic-assessment-of-the-health-benefits-of-walking-on-the-wales-coast-path.pdf?rnd=132064934010000000

Cumbers, A., Shaw, D., Crossan, J., & McMaster, R. (2018). The Work of Community Gardens: Reclaiming Place for Community in the City. *Work, Employment and Society*, *32*(1), 133–149. https://doi.org/10.1177/0950017017695042

Fairbrass A, Chatterjee H, Jones K, Osborn D. Human responses to nature- and culture-based non-clinical interventions: a systematised review. *Perspectives in Public Health*, December 2020. doi:10.1177/1757913920967036

Gunning-Schepers, L. (1988). *The health benefits of prevention: a simulation approach*. Erasmus University Rotterdam. [PDF] The health benefits of prevention: a simulation approach. | Semantic Scholar

Howarth, M., Griffiths, A., da Silva, A. & Green, R. (2020). Social prescribing: a 'natural' community-based solution. *British Journal of Community Nursing*, 25:6, 294-298.

Hunter and colleagues for World Health Organization (2017) *Urban green space interventions and health. A review of impacts and effectiveness*. WHO:Geneva. http://www.euro.who.int/en/health-topics/environment-and-health/urbanhealth/publications/2017/urban-green-space-interventions-and-health-a-review-of-impacts-andeffectiveness.-full-report-2017

Husk K, Lovell R, Cooper C et al. Participation in environmental enhancement and conservation activities for health and well-being in adults: a review of quantitative and qualitative evidence. *Cochrane Database Syst Rev* 2016;5:CD010351

International Physical Activity Questionnaire (IPAQ). (nd). Website for open access to questionnaire and scoring protocol. https://sites.google.com/site/theipaq/

Jenkinson, C.E., Dickens, A.P., Jones, K. et al. Is volunteering a public health intervention? A systematic review and meta-analysis of the health and survival of volunteers. *BMC Public Health*, 13, 773 (2013). https://doi.org/10.1186/1471-2458-13-773

Lovell, R., Wheeler, B., Husk, K., Machray, K & Depledge, M. (2019). What Works briefing on natural environment based health interventions. Report for DEFRA. Available at http://randd.defra.gov.uk

Maund, P., Irvine, K., Reeves, J., Strong, E., Cromie, R., Dallimer, M. & Davies. (2019). Wetlands for Wellbeing: Piloting a Nature-Based Health Intervention for the Management of Anxiety and Depression. *International Journal of Environmental Research and Public Health*, 16. 4413. 10.3390/ijerph16224413.

Mayer, FS. & Frantz, CM. (2004). The connectedness to nature scale: A measure of individuals' feeling in community with nature. *Journal of Environmental Psychology*, 24(4), 503-515.

Mygind L, Kjeldsted E, Hartmeyer RD, Mygind E, Bølling M and Bentsen P (2019) Immersive Nature-Experiences as Health Promotion Interventions for Healthy, Vulnerable, and Sick Populations? A Systematic Review and Appraisal of Controlled Studies. *Front. Psychol*. 10:943. doi:10.3389/fpsyg.2019.00943

Mygind L, Kjeldsted E, Hartmeyer RD, Mygind E, Bølling M and Bentsen P (2019) Immersive Nature-Experiences as Health Promotion Interventions for Healthy, Vulnerable, and Sick Populations? A Systematic Review and Appraisal of Controlled Studies. *Front. Psychol*. 10:943. doi:10.3389/fpsyg.2019.00943

NEAR Health (2020). *Nature and Environment to Attain and Restore Health Toolkit*. Environmental Protection Agency, Johnstown Castle, Ireland.

Plunz, R., Zhou, Y., Vintimilla, MIC., McKeown, K., Yu, T., Uguccioni, L. & Sutto, MP. (2019). Twitter sentiment in New York City parks as measure of well-being. *Landscape and Urban Planning*, 189, 235-246. https://doi.org/10.1016/j.landurbplan.2019.04.024

Pritchard, A., Richardson, M., Sheffield, D., & McEwan, K. (2019) The relationship between nature connectedness and eudaimonic well-being: A meta-analysis. *Journal of Happiness Studies*.

Richardson, M. & McEwan, K. (2018). 30 Days Wild and the Relationships Between Engagement With Nature's Beauty, Nature Connectedness and Well-Being. *Frontiers in Psychology*, 9. https://www.frontiersin.org/article/10.3389/fpsyg.2018.01500

Richardson, M., Hunt, A., Hinds, J., Bragg, R., Fido, D., Petronzi, D., Barbett, L., et al. (2019). A Measure of Nature Connectedness for Children and Adults: Validation, Performance, and Insights. *Sustainability*, *11*(12), 3250. MDPI AG. Retrieved from http://dx.doi.org/10.3390/su11123250

Richardson, M., Passmore, H-A., Lumber, R., Thomas, R., & Hunt, A.(2021). Moments, not minutes: The nature-wellbeing relationship. *International Journal of Wellbeing*, 11(1), 8-33. https://doi.org/10.5502/ijw.v11i1.1267

Salazar, G., Kunkle, K. & Monroe, M. C. (2020). *Practitioner guide to assessing connection to nature*. Washington, DC: North American Association for Environmental Education.

Saran, T., Owoc, J., & Bojar, I. (2018). Use of the IPAQ questionnaire in the form of a mobile application in monitoring physical activity of patients with cardiovascular diseases. *Annals of agricultural and environmental medicine : AAEM*, 25 3, 395-402 .

Sasidharan, V. & McKenzie, T. (nd). *SOPARNA: System for Observing Physical Activity and Recreation in Natural Areas - Description and Procedures Manual*. San Diego State University, US. https://activelivingresearch.org/sites/activelivingresearch.org/files/SOPARNA_Protocols_04.30.14_0.pdf

Shanahan DF, Astell-Burt T, Barber EA, Brymer E, Cox DTC, Dean J, Depledge M, Fuller RA, Hartig T, Irvine KN, Jones A, Kikillus H, Lovell R, Mitchell R, Niemelä J, Nieuwenhuijsen M, Pretty J, Townsend M, van Heezik Y, Warber S, Gaston KJ. Nature-Based Interventions for Improving Health and Wellbeing: The Purpose, the People and the Outcomes. *Sports* (Basel). 2019 Jun 10;7(6):141. doi: 10.3390/sports7060141. PMID: 31185675; PMCID: PMC6628071

Twohig-Bennet, C., & Jones, A. (2018). The health benefits of the great outdoors: A systematic review and meta- analysis of greenspace exposure and health outcomes. Environmental Research, 166, 628–6237. https://doi.org/10.15124/CRD42015025193

Topp C, W, Østergaard S, D, Søndergaard S, Bech P. (2015). The WHO-5 Well-Being Index: A Systematic Review of the Literature. *Psychotherapy and Psychosomatics*, 84, 167-176. doi: 10.1159/000376.

van den Bosch, M., Ode Sang, A. Urban natural environments as nature-based solutions for improved public health – A systematic review of reviews, *Environmental Research*, 158, 2017, p373-384. https://doi.org/10.1016/j.envres.2017.05.040

Vert, C., Carrasco-Turigas, G., Zijlema, W., Espinosa, A., Cano-Riu, L., Elliott, L.R., Litt, J., Nieuwenhuijsen, M.J., Gascon, M. (2019a). Impact of a riverside accessibility intervention on use, physical activity, and wellbeing: A mixed methods pre-post evaluation. *Landscape and Urban Planning*, 190, 103611. https://doi.org/10.1016/j.landurbplan.2019.103611

Vert, C., Nieuwenhuijsen, M., Gascon, M., Grellier, J., Fleming, L. E., White, M. P., & Rojas-Rueda, D. (2019b). Health Benefits of Physical Activity Related to an Urban Riverside Regeneration. *International journal of environmental research and public health*, *16*(3), 462.

Ward Thompson, C. & Roe, J. (2010). *Tools for evaluating the impact of WIAT (Woods in and Around Towns) Intervention sites: Protocol to be followed when using the WIAT Questionnaire and Environmental Audit Tools.* Report for Forestry Commission Scotland. OPENspace: Edinburgh College of Art.

Ward Thompson, C., Roe, J. & Aspinall, P. (2010). *Woods In and Around Towns (WIAT): a longitudinal study comparing perceptions and use of woodlands pre and post-intervention (2006-2009).* Report for Forestry Commission Scotland. OPENspace: Edinburgh College of Art.

Ward Thompson C, Silveirinha de Oliveira E, Tilley S, Elizalde A, Botha W, Briggs A, et al. Health impacts of environmental and social interventions designed to increase deprived communities' access to urban woodlands: a mixed-methods study. *Public Health Res*, 2019:7(2)

Warwick Medical School (2020). The Warwick-Edinburgh Mental Wellbeing Scales – WEMWBS. Website with background and guidance to use of tools. https://warwick.ac.uk/fac/sci/med/research/platform/wemwbs/

Wheeler, W., Gordon-Brown, H., Lovell, R., (2020) *Making the Most of Green Space for People's Health.* European Centre for Environment and Human Health, University of Exeter.

White, M.P. et al. (2019) Spending at least 120 minutes a week in nature is associated with good health and wellbeing. *Scientific Reports*, 9, 7730. https://doi.org/10.1038/s41598-019-44097-3

White, M.P., Elliott, L.R., Grellier, J. *et al.* (2021). Associations between green/blue spaces and mental health across 18 countries. *Scientific Reports*, 11**,** 8903. https://doi.org/10.1038/s41598-021-87675-0

WHO (no date) Examples of applications of the health economic assessment tool (HEAT) for cycling. Available from https://www.euro.who.int/en/health-topics/environment-and-health/Transport-and-health/activities/guidance-and-tools/health-economic-assessment-tool-heat-for-cycling-and-walking/examples-of-applications-of-the-health-economic-assessment-tool-heat-for-walking-and-cycling [Accessed 22 April 2021].

WHO ( ) Health economic assessment tool (HEAT) for walking and for cycling. Available from: https://www.euro.who.int/__data/assets/pdf_file/0010/352963/Heat.pdf [Accessed 22 April 2021].

Citation: Edwards-Jones, A., Fileman, E., Abrahams, R., & Wheeler, B. (2022). *Economic and non-economic measures and tools for evaluating the health and wellbeing benefits of nature based health interventions.*

SWEEP Resource for the Investing in Nature for Health project, part of the South West Environment and Economic Prosperity (SWEEP) programme.

SWEEP is a partnership between the University of Exeter, the University of Plymouth and Plymouth Marine Laboratory.

Funded by NERC, it brings together experts and stakeholders to solve key challenges faced by those working with our natural resources.

sweep
Investing in Nature for Health
RESOURCE

Evaluating interventions in green space: Derriford Community Park, Plymouth, Devon

This report was produced in collaboration with
Plymouth City Council

PLYMOUTH
CITY COUNCIL

Who should read this?

This information is relevant to individuals and organisations planning or implementing interventions in green spaces, whether they are from the environmental management, urban planning, public health or voluntary sectors. It will also be of interest to funders and policy makers working in this space.

Why this resource matters

The health benefits of people spending time in greenspace has become increasingly well evidenced (Wheeler et al. 2020). This has resulted in a growing number of environmental projects aimed at improving public health through a variety of interventions. Examples include enhancements to the quality of greenspace (whether ecological or in relation to the physical infrastructure), increasing availability and access to greenspaces, and the introduction of new programmes aiming to increase their use.

To understand the effectiveness of these projects, it is essential that appropriate measures are used to evaluate the benefits they deliver. Whilst improved health and wellbeing may be their ultimate aim, it is not always appropriate or achievable to measure health outcomes directly. This is due to a variety of factors such as the intangible nature of some health outcomes, the ethical issues involved in collecting and using sensitive personal health data, and the long-time frames often required to deliver interventions that lead to health outcomes. Alternative measures may need to be considered, therefore, such as the use of secondary, intermediate outcomes or proxies, where pathways between impacts of the intervention and health outcomes are known. A good example is between increased levels of physical activity and more immediate impacts to mental health (Hunter et al. 2017).

There is now a growing need, both from practitioners and funders, to draw on the best available evidence around evaluation metrics, and approaches, suitable for evaluating the impacts and outcomes of programmes that invest in the environment for health outcomes.

What is this resource about – and what is its value?

Using Plymouth City Council's Green Minds Derriford Community Park project as a case study, this resource draws on relevant available evidence to set out known pathways through which greenspace interventions may benefit human health. The resource uses a causal loop diagram to display the pathways between interventions and their intermediate and final outcomes, as well as the key influencing factors for success. Also included is a table of measures which could be used to evaluate the success of these interventions, and some case studies highlighting examples of where these measures have been used.

This resource is of direct value to Derriford Community Park but also has wider applicability to others working in this field.

"As manager of a strategic, new city greenspace we're committed to maximising the health and wellbeing outcomes for our local communities. This approach is already helping us identify and focus our resources on key intermediate health and wellbeing outcomes; and to ensure we have the most effective tools to capture our impact.'

Jerry Griffiths, Project Manager at Derriford Community Park

It introduces an approach that promotes a shared understanding of the complex connections between interventions and outcomes, which in turn supports the development and implementation of projects, programmes and partnerships that protect and improve the natural environment and human health and wellbeing. Crucially, the resource also examines some of the best evidence around how to measure and evaluate success.

Causal loop diagrams are used in many disciplines to help visualise how variables are related to one another. Through the use of shareable, online, visual tools, causal loop diagrams can be dynamic and responsive, and if developed collaboratively with projects stakeholders, have the potential to deliver multiple benefits such as:

- Engaging wider stakeholders - especially hard to reach groups.
- Enabling shared discussions and understanding.
- Supporting more effective and collaborative project planning and tracking.
- Acting as a visual communication tool to help strengthen funding applications and support decision making, by clearly showing the links between planned interventions, outcomes and influencing factors for success.
- Demonstrating value for money associated with interventions, especially where there are multiple benefits.

Plymouth City Council's Green Minds Derriford Community Park

Derriford Community Park is a 146-hectare green space in the northeast of Plymouth, South West England. As a high quality multi-functional greenspace, it aims to provide a new city-wide destination for environmental learning, recreation, and large-scale habitat restoration. The park will benefit the health and wellbeing of local residents, as well as visitors from further away.

There are three key interventions taking place at Derriford Community Park:

1. Physical infrastructure – a new 5.6 mile off-road cycling and footpath network; the construction of a community centre with space to view wildlife; signage; and interpretation boards.

2. Ecological enhancement – including nature-based solutions to reduce noise and air pollution; a whole ecosystem approach to habitat and biodiversity enhancement involving the use of climate resilient plant species; rewilding activities including beaver reintroduction.

3. Activities and engagement – practical groups and voluntary conservation activities; family engagement events and citizen science events such as Bioblitz.

Developing and understanding causal loop diagrams

These three interventions have been represented in the Green Minds Derriford Community Park Project Causal Loop Diagram (Fig 1). This is also available online in an interactive format. This casual loop diagram describes the different components of the greenspace interventions and how they interact with each other, highlighting the complexity of these interventions. The key elements shown in the map are:

- The three main types of intervention occurring in Derriford Community Park (as outlined above) - physical infrastructure, ecological enhancement, and activities and engagement.
- The outcomes these interventions are linked to - physical health, mental health, and nature connection.
- The key factors for intervention success - predominantly around community engagement and buy in.

(Fig.2) shows the physical infrastructure casual loop diagram. This has been extracted from the overall Green Minds Derriford Community Park Project Causal Loop Diagram (Fig 1) and shows how different sections of the causal loop diagram can be looked at separately to understand specific intervention and their intermediate outcomes.

It is important to note that the diagrams are simplified versions of reality; representing just the key interventions, connections, and outcomes at one point in time. To further enhance their value, additional connections could be added, as well as other potentially useful information such as on the strength and quality of the relationships.

These diagrams are best used iteratively. This resource can be complemented by use of a Dynamic Mapping resource (see SWEEP's resource, Understanding environmental investment for health in the South West), which illustrates the links and funding streams between stakeholder groups involved in nature-based health programme.

How to use the online Causal Loop Diagram

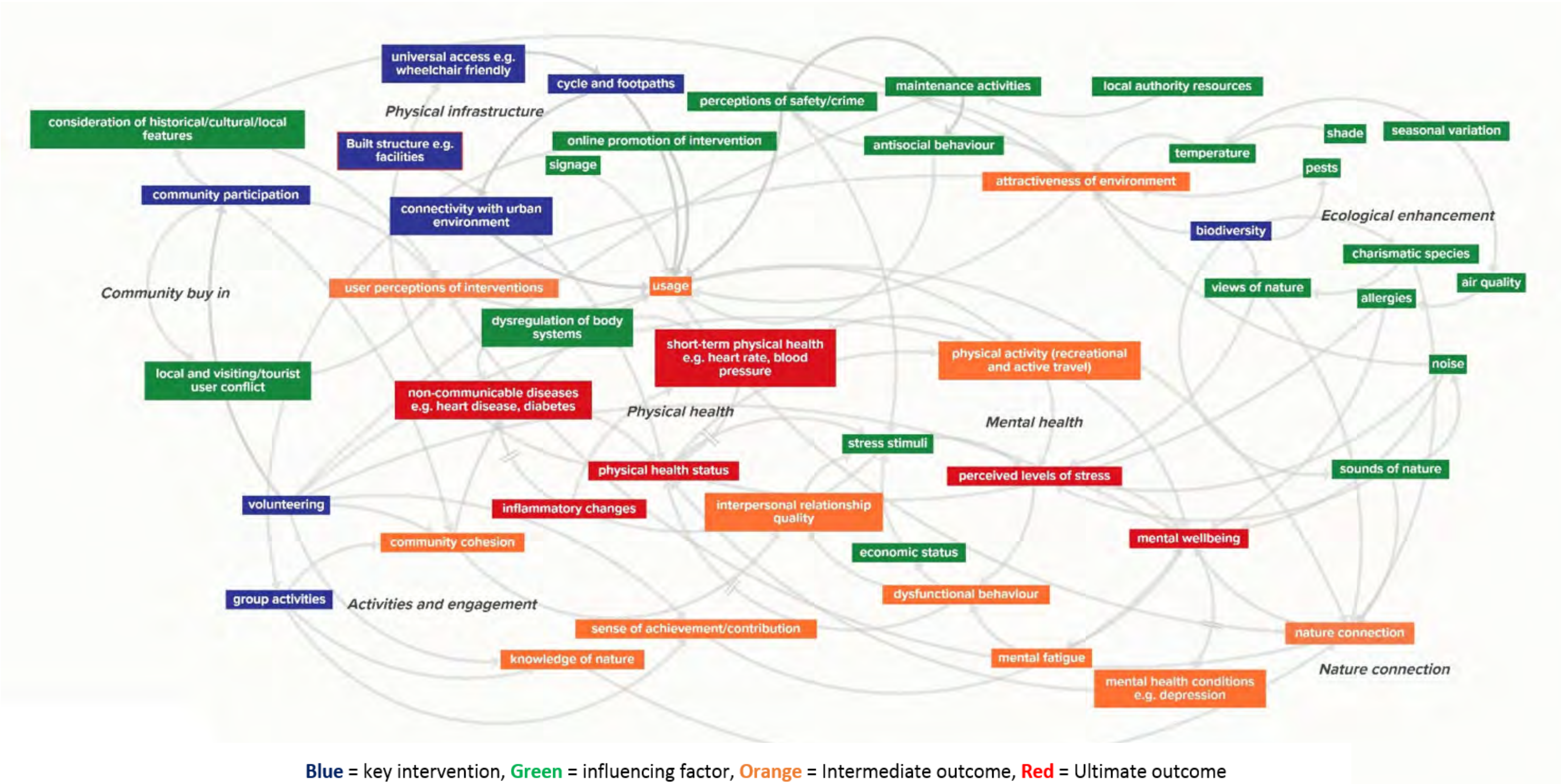
The Green Minds Derriford Community Park Project Causal Loop Diagram is available online in an interactive format.

When the map has opened in your browser, use the navigation bar, top left to zoom in and out.

To see a section of the map, hover your mouse over a word (node) and it will show only the other areas directly linked to it. An example of this is included in this resource (Fig.2 and Fig.3).

Fig. 1 Green Minds Derriford Community Park Project Causal Loop Diagram

This diagram demonstrates the complexity of the relationships between community buy in, physical infrastructure, activities and engagement, physical health, ecological enhancement, mental health, and nature connection.



Blue = key intervention, **Green** = influencing factor, **Orange** = Intermediate outcome, **Red** = Ultimate outcome

// represents a delay in the relationship i.e. it may take a long time for an intervention to create change in a particular outcome.

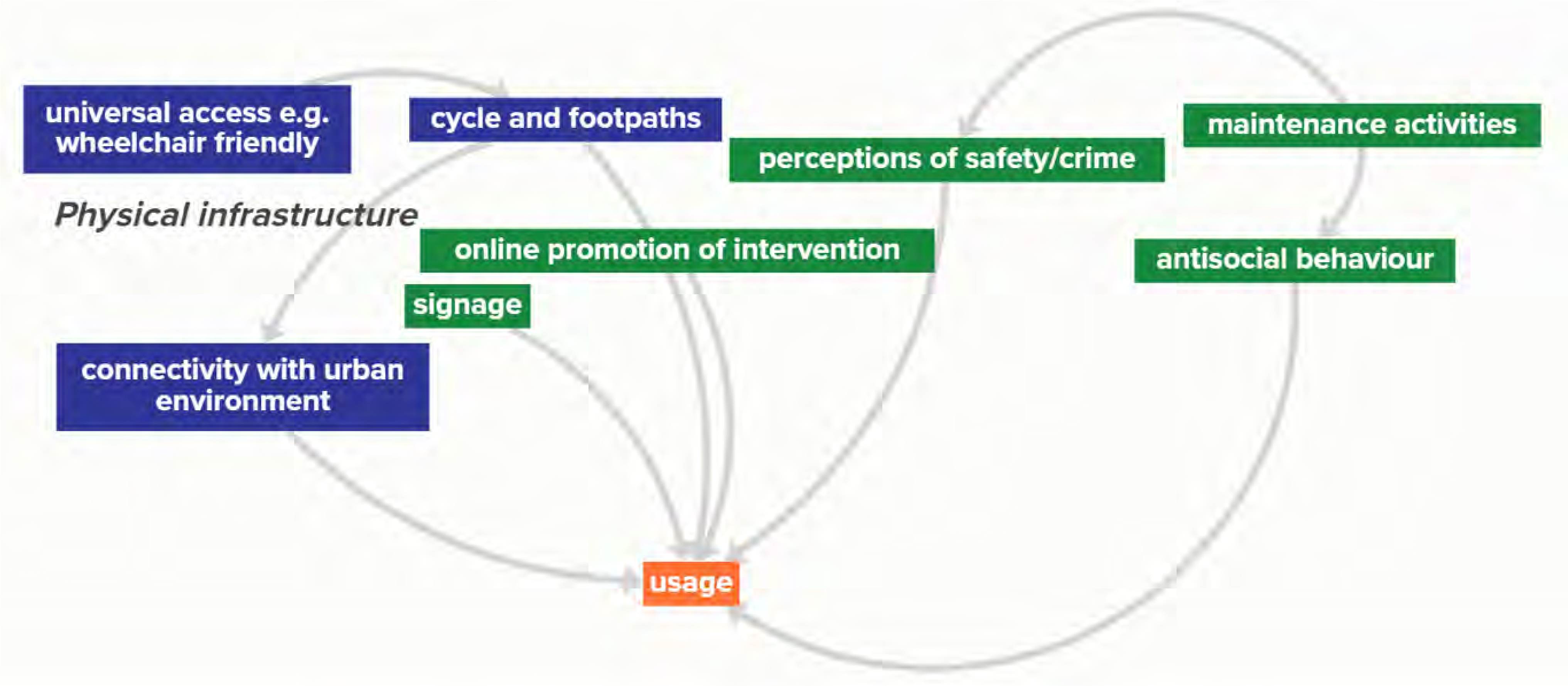
Arrows represent the direction of the relationship e.g. biodiversity affects the attractiveness of the environment to people.

Fig.2 Physical infrastructure casual loop diagram showing intermediate outcomes

This is one section of the Plymouth City Council's Green Minds Derriford Community Park Project Causal Loop Diagram.

It shows the direct variables linked to physical infrastructure and includes the key interventions, influencing factors and the intermediate outcomes. This diagram shows the intermediate outcomes, which are measurable, and that will lead to the associated ultimate outcomes (shown in Fig 3), which tend to be more difficult to measure.

The influencing factors show those aspects key for successful intervention delivery.



Blue = key intervention, Green = influencing factor, Orange = Intermediate outcome, Red = Ultimate outcome

Arrows represent the direction of the relationship e.g. biodiversity affects the attractiveness of the environment to people.

Fig.3 Physical infrastructure causal loop diagram showing ultimate outcomes

This diagram follows on directly from Figure 2 and shows how the intermediate outcome 'usage' of physical infrastructure links to the four ultimate outcomes (shown in red).

Blue = key intervention, Green = influencing factor, Orange = Intermediate outcome, Red = Ultimate outcome

Arrows represent the direction of the relationship e.g. biodiversity affects the attractiveness of the environment to people.

How has this been applied to the Derriford Community Park project?

The process of creating the causal loop diagrams has supported the project delivery group to:

- develop a shared understanding around the health and wellbeing links to the project.
- interrogate assumptions around health and wellbeing outcomes, identifying challenges and risks as well as opportunities.
- demonstrate the value of particular interventions and the use of appropriate and practicable measurement tools of the identified outcomes.

The map will also be used as a visual tool with funders and decision makers to demonstrate the multiple benefits being delivered by the project and how health and wellbeing can deliver real value for money.

How can we measure the health impacts of interventions?

There are many pathways to achieving physical and mental health through the delivery of greenspace interventions including physical activity, social interaction, and psychological factors such as personal restoration or enjoyment of the intervention (Fairbrass et al. 2020). Causal loop diagrams have the advantage of showing intermediate outcomes, that link interventions and ultimate health outcomes. These intermediate outcomes are usually more measurable than the longer-term goals of achieving and evidencing improvements in physical and mental health. As a result, they can offer a more realistic, short-term indication of how successful any particular intervention is.

Table 1 highlights some of the key evaluation measures and methods for both intermediate and ultimate health. Whether measuring health outcomes or intermediate steps, it is important to consider not just how the space is being used but also who is using it and their sociodemographic groups (Hunter et al., 2017).

Table 1. Key evaluation measures and methods for both intermediate and ultimate health

Evaluation measure	Description	Method	Resources
Use of green space Visit frequency/time in nature	Spending time in nature is associated with mental well-being (White et al. 2019). Nationally representative surveys such as the Monitor of Engagement with the Natural Environment (MENE) survey ask visitors to self-report how often they visit nature and the duration of their last visit to nature.	Survey	MENE technical report, including survey questions
Evaluation of site quality and experience WIAT (Woods in and around Towns) Environmental Audit Tool	Use of various measures to assess the quality of a green/blue space, and user experience of the space. May typically be done via longitudinal methods i.e. before and after a change to the site (environmental intervention). Combines an environmental audit and survey questionnaire to assess woodland site interventions. Inc. measures of wellbeing, physical health, perceived stress, nature connectedness, general health, social capital, and perceptions of environment.	Environmental audit (professional and/or community); Survey questionnaire	Protocol for WIAT questionnaire and audit tool Report: overview of WIAT
System for Observing Parks and Recreation in Communities (SOPARC)	A validated tool for assessing activities within parks, involving observation of users' physical activity levels, type of use, and demographics e.g. gender. It also collects information on the area's characteristics e.g. accessibility.	Observation	SOPARC App (online app no longer available but guides are) SOPARC User Guides
SOPARNA	An adaptation of SOPARC for measuring recreation- and physical activity-related behaviour in natural open spaces. Measures level of physical activity in relation to specific environmental features	Observation	SOPARNA description and procedures manual
Physical activity World Health Organisation Health Economic Assessment Tool (HEAT)	HEAT calculates the reduction in mortality, and value of this reduction, resulting from walking and cycling. It can assess current levels and changes over time, as well as evaluating projects. Data is needed on the size of the population and the amount of time people walk or cycle in the space being assessed.	Observation	HEAT HEAT Methods and User Guide
International Physical Activity Questionnaire (IPAQ) *See also SOPARC*	Measures health-related physical activity in populations. Long and short versions. Can be self-administered.	Survey	IPAQ questionnaire and scoring guide

Table 1. Key evaluation measures and methods for both intermediate and ultimate health (continued)

Evaluation measure	Description	Method	Resources
Mental wellbeing			
WHO-5	A measure of current wellbeing, consisting of five statements which are rated on a scale.	Survey	WHO-5 questionnaire Review showing validity of WHO-5
ONS-4	As with the WHO-5, the ONS-4 are four statements that are rated on a scale. They measure three aspects of wellbeing: life satisfaction, feeling that life is worthwhile, and wellbeing in the moment (feelings of happiness and anxiety)	Survey	ONS Personal well-being user guidance
WEMWBS	A measure of mental wellbeing with two scales, a 14-item and shorter 7-item scale (SWEMWBS). Applied widely and in various settings. Good for evaluating interventions/projects	Survey	WEMWBS Overview and guide to use Paper: Wetlands for Wellbeing Paper: Social prescription referrals to Wellbeing Garden NBS Appendix, section 21
Other relevant scales e.g. Perceived Stress Scale, Perceived Restorativeness Scale			
Social Media	Use of social media platforms to record sentiment as a measure of wellbeing	Quantitative analysis of tweets	Paper: Twitter sentiment to measure wellbeing of public park users
Nature connection			
Connection to nature	Nature connection is associated with health outcomes such as happiness and wellbeing as well as pro-environmental behaviours e.g. (Capaldi et al. 2014; Pritchard et al. 2019). There are several validated scales which can be used to measure nature connection e.g. Nature Connection Index (NCI); Connectedness to Nature Scale (CNS), Inclusion of Nature in Self Scale (INS)	Survey	Paper: Connectedness to Nature Scale Connectedness to Nature Scale survey questions Paper: Nature Connection Index Paper: 30 Days Wild evaluation for Wildlife Trusts UK government NCI dataset NBS Appendix, p1038

Table 1. Key evaluation measures and methods for both intermediate and ultimate health (continued)

Evaluation measure	Description	Method	Resources
Nature connection			
NEAR Health toolkit	Incorporates several measures (ONS-4, NCI, MENE) in a before and after questionnaire to assess how blue and green nature-based activities impact on changes in various aspects of people's lives. A 5-point scale version for children was also produced..	Survey	Research 348 Toolkit: Connecting with Nature for Health and Wellbeing
Engagement with nature	A simple measure of nature connection which ask about activities e.g. smelling wildflowers.	Survey	Paper: Engagement with nature
Pro-nature Conservation Behaviour Scale	A validated scale which measures active behaviours that support the conservation of biodiversity e.g. volunteering, litter-picking.	Survey	Pro-nature Conservation Behaviour Scale Paper: Pro-nature Conservation Behaviour Scale Blog: Pro-nature Conservation Behaviour Scale
Community cohesion			
Nature Prescriptions	Green prescribing, such as gardening, can be used as a non-medical asset-based approach by health professionals working in the community as a way to promote health and wellbeing.	Green prescription	Community wellbeing
See also SOPARC	One pathway for connecting physical health and public parks is through collective efficacy where neighbourhood parks act as a hub for social cohesion.	Observation	SOPARC App (online app no longer available but guides are) SOPARC User Guides
See also WIAT	The protocol followed for environmental audit of a green space in this case focuses on a community-level evaluation of WIAT interventions aimed at improving woodlands so as, ultimately, to improve people's quality of life.	Environmental audit	
Acceptability of intervention			
Sense of empowerment		Survey	NBS Appendix, p834
Trust		Survey	NBS Appendix, p848
Transparency of co-production		Survey	NBS Appendix, p881

Case studies - where have some of these evaluations been applied?

Causal Loop Diagrams

Where? Bradano River, Italy

What? Enhanced decision-making on sustainable management solutions to flooding of the river

Data collection and measures Interviews with stakeholders were used to build individual CLDs, these were integrated into a single CLD by the researchers which was discussed in a workshop with stakeholders. This CLD was then simplified for use in decision-making by the researchers, with this version given final approval by stakeholders. particularly communication between stakeholders and authorities.

Findings

Stakeholders felt the CLD:

- Facilitated stakeholder discussion e.g. helped bridge the communication gap between policymakers and local stakeholders such as farmers
- Improved the role of stakeholders in decision-making, incorporating their specific and local knowledge.
- Developed an integrated perspective on a complex issue, increasing awareness of the problem and interaction between system components, improving understanding of socio-economic and environmental interactions

https://www.sciencedirect.com/science/article/pii/S0022169419310893?via%3Dihub#s0065

Other successful examples include the construction of a CLD linking housing, energy and wellbeing, involving 50 UK stakeholders. By the end of the process stakeholders were discussing policy options https://ehjournal.biomedcentral.com/articles/10.1186/s12940-016-0098-z

World Health Organisation Health Economic Assessment Tool (HEAT)

Where? Wales

What? Assessment of the value of walking on the coast path (Cavil et al. 2014)

Data collection and measures Used the World Health Organization's Health Economic Assessment (HEAT) tool to conduct an economic assessment of the health benefits arising from people walking regularly on the Wales Coast Path. Used data from counters on the path, and user surveys

Findings

- 23,688 people walked on the path every week. On average they walked 4.38 miles per week (spread over a mean of 1.6 visits per week).
- This level of walking prevented 7 deaths per year among the walking population, compared to people who do not walk regularly.
- An economic value can be calculated in relation to the number of deaths prevented, using 'statistical life'. Based on this, the economic value of the health benefits of walking on the Wales Coast Path is £18.3m per year.

- £3.5m of benefit per year can be directly attributed to the existence of the Wales Coast Path.

https://www.euro.who.int/en/health-topics/environment-and-health/Transport-and-health/activities/guidance-and-tools/health-economic-assessment-tool-heat-for-cycling-and-walking/examples-of-applications-of-the-health-economic-assessment-tool-heat-for-walking-and-cycling/united-kingdomwales-affirming-the-value-of-walking-on-the-wales-coast-path

System for Observing Parks and Recreation in Communities (SOPARC)

Where? Barcelona, Spain

What? Evaluation of an urban riverside regeneration project which aimed to improve access for pedestrians and cyclists (Vert et al. 2019)

Data collection and measures Used data from Barcelona local authorities and meta-analysis assessing physical activity and health outcomes to develop and apply the "Blue Active Tool".

Findings

- Estimated that 5753 adult users visited the riverside park daily and performed different types of physical activity
- Estimated an annual reduction of 7.3 deaths and 6.2 cases of diseases, corresponding to 11.9 DALYs and an annual health-economic impact of 23.4 million euros.

This project was part of BlueHealth which has measured the impact of a range of interventions.

Mental health and wellbeing

Where? UK

What? A case study based on the example of gardening as a nature-based social prescription provided by the RHS Bridgewater Wellbeing Garden.

Data collection and measures 47 people were referred to the Wellbeing Garden. The participants' mental wellbeing was scored and recorded before and after attending the Wellbeing Garden using a short version of the validated Warwick-Edinburgh Mental Well-being Scale (SWEMWBS).

Findings 12% increase in those recorded as having high wellbeing after intervention; 20% decrease in those recorded as having low wellbeing after intervention.

https://www.magonlinelibrary.com/doi/full/10.12968/bjcn.2020.25.6.294

Nature Connection

Where? UK

What? Evaluation of the Wildlife Trust's 30 Days Wild campaign effectiveness in improving public engagement with nature

Data collection and measures University of Derby evaluated survey responses from more than 1,000 people over five years

Findings

- 30 Days Wild resulted in very significant increases in nature connectedness for those who began with a weak connection to nature – their nature connectedness rose by 56%
- 30 Days Wild boosted the health of participants by an average of 30%.
- 30 Days Wild made people, particularly those who started with a relatively weak connection to nature, significantly happier
- 30 Days Wild inspired significant increases in pro-nature behaviour

doi:10.1108/JPMH-02-2018-0018.

doi:10.3389/fpsyg.2018.01500.

https://www.wildlifetrusts.org/30-days-wild-5-year-review

Green/Blue Prescriptions

Where? UK

What? A case study based on the example of gardening, as a nature- based social prescription, provided by the RHS Bridgewater Wellbeing Garden.

Data collection and measures Questionnaire using short WEMWBS scale following referral to therapeutic gardening activity.

Findings Made a case for gardening as a social prescription. Illustrates the scope, reach and impact of non-medical, salutogenic approaches for community practitioners.

https://www.magonlinelibrary.com/doi/full/10.12968/bjcn.2020.25.6.294?rfr_dat=cr_pub+
+0pubmed&url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org

References

Association for Consultancy and Engineering (2020). Measures for successful outcomes: the five capitals approach - A discussion paper. https://www.acenet.co.uk/media/5151/ace-five-capitals-report-2020.pdf

Capaldi, C. A., Dopko, R. L., Zelenski, J. M. (2014) The relationship between nature connectedness and happiness: a meta-analysis. Frontiers in Psychology, 5, 976. https://doi.org/10.3389/fpsyg.2014.00976

Carlin, C., Kindermann, G., Britton, E., Cormican, M., Domegan, C., Gormally, M. & O'Donovan, D. (2020). Research 348 Toolkit: Connecting with Nature for Health and Wellbeing. Report prepared for the Environmental Protection Agency by the NEAR Health Project Team, NUI Galway.

Cavil, N., H. Rutter, and R. Gower (2014) Economic assessment of the health benefits of walking on the Wales Coast Path. http://publications.naturalengland.org.uk/publication/4513819616346112

Fairbrass A, Chatterjee H, Jones K, Osborn D. Human responses to nature- and culture-based non-clinical interventions: a systematised review. Perspectives in Public Health. December 2020. doi:10.1177/1757913920967036

Howarth, M., Griffiths, A., da Silva, A. & Green, R. (2020). Social prescribing: a 'natural' community-based solution. British Journal of Community Nursing, 25:6, 294-298.

Hunter and colleagues for World Health Organization (2017) Urban green space interventions and health. A review of impacts and effectiveness. WHO:Geneva. http://www.euro.who.int/en/health-topics/environment-and-health/urbanhealth/publications/2017/urban-green-space-interventions-and-health-a-review-of-impacts-andeffectiveness.-full-report-2017

Husk K, Lovell R, Cooper C et al. Participation in environmental enhancement and conservation activities for health and well-being in adults: a review of quantitative and qualitative evidence. Cochrane Database Syst Rev 2016;5:CD010351

International Physical Activity Questionnaire (IPAQ). (nd). Website for open access to questionnaire and scoring protocol. https://sites.google.com/site/theipaq/

Jenkinson, C.E., Dickens, A.P., Jones, K. et al. Is volunteering a public health intervention? A systematic review and meta-analysis of the health and survival of volunteers. BMC Public Health 13, 773 (2013). https://doi.org/10.1186/1471-2458-13-773

Maund, P., Irvine, K., Reeves, J., Strong, E., Cromie, R., Dallimer, M. & Davies. (2019). Wetlands for Wellbeing: Piloting a Nature-Based Health Intervention for the Management of Anxiety and Depression. International Journal of Environmental Research and Public Health. 16. 4413. 10.3390/ijerph16224413.

Mygind L, Kjeldsted E, Hartmeyer RD, Mygind E, Bølling M and Bentsen P (2019) Immersive Nature-Experiences as Health Promotion Interventions for Healthy, Vulnerable, and Sick Populations? A Systematic Review and Appraisal of Controlled Studies. Front. Psychol. 10:943. doi:10.3389/fpsyg.2019.00943

Plunz, R., Zhou, Y., Vintimilla, MIC., McKeown, K., Yu, T., Uguccioni, L. & Sutto, MP. (2019). Twitter sentiment in New York City parks as measure of well-being. Landscape and Urban Planning, 189, 235-246. https://doi.org/10.1016/j.landurbplan.2019.04.024.

Pritchard, A., Richardson, M., Sheffield, D., & McEwan, K. (2019) The relationship between nature connectedness and eudaimonic well-being: A meta-analysis. Journal of Happiness Studies.

References

Sasidharan, V. & McKenzie, T. (nd). SOPARNA: System for Observing Physical Activity and Recreation in Natural Areas - Description and Procedures Manual. San Diego State University, US.

Shanahan DF, Astell-Burt T, Barber EA, Brymer E, Cox DTC, Dean J, Depledge M, Fuller RA, Hartig T, Irvine KN, Jones A, Kikillus H, Lovell R, Mitchell R, Niemelä J, Nieuwenhuijsen M, Pretty J, Townsend M, van Heezik Y, Warber S, Gaston KJ. Nature-Based Interventions for Improving Health and Wellbeing: The Purpose, the People and the Outcomes. Sports (Basel). 2019 Jun 10;7(6):141. doi: 10.3390/sports7060141. PMID: 31185675; PMCID: PMC6628071.

Twohig-Bennet, C., & Jones, A. (2018). The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. Environmental Research, 166, 628–6237. https://doi.org/10.15124/CRD42015025193

van den Bosch, M., Ode Sang, A. Urban natural environments as nature-based solutions for improved public health – A systematic review of reviews, Environmental Research, 158, 2017, p373-384. https://doi.org/10.1016/j.envres.2017.05.040.

Vert, C., Carrasco-Turigas, G., Zijlema, W., Espinosa, A., Cano-Riu, L., Elliott, L.R., Litt, J., Nieuwenhuijsen, M.J., Gascon, M. Impact of a riverside accessibility intervention on use, physical activity, and wellbeing: A mixed methods pre-post evaluation, Landscape and Urban Planning, 190, 2019, 103611. https://doi.org/10.1016/j.landurbplan.2019.103611.

Ward Thompson, C. & Roe, J. (2010). Tools for evaluating the impact of WIAT (Woods in and Around Towns) Intervention sites: Protocol to be followed when using the WIAT Questionnaire and Environmental Audit Tools. Report for Forestry Commission Scotland. OPENspace: Edinburgh College of Art.

Ward Thompson, C., Roe, J. & Aspinall, P. (2010). Woods In and Around Towns (WIAT): a longitudinal study comparing perceptions and use of woodlands pre and post□intervention (2006□2009). Report for Forestry Commission Scotland. OPENspace: Edinburgh College of Art.

Ward Thompson C, Silveirinha de Oliveira E, Tilley S, Elizalde A, Botha W, Briggs A, et al. Health impacts of environmental and social interventions designed to increase deprived communities' access to urban woodlands: a mixed-methods study. Public Health Res 2019;7(2)

Warwick Medical School (2020). The Warwick-Edinburgh Mental Wellbeing Scales – WEMWBS. Website with background and guidance to use of tools. https://warwick.ac.uk/fac/sci/med/research/platform/wemwbs/

Wheeler, W., Gordon-Brown, H., Lovell, R., (2020) Making the Most of Green Space for People's Health. European Centre for Environment and Human Health, University of Exeter

White, M.P. et al. (2019) Spending at least 120 minutes a week in nature is associated with good health and wellbeing. Scientific Reports, 9, 7730. https://doi.org/10.1038/s41598-019-44097-3

WHO (no date) Examples of applications of the health economic assessment tool (HEAT) for cycling. Available from https://www.euro.who.int/en/health-topics/environment-and-health/Transport-and-health/activities/guidance-and-tools/health-economic-assessment-tool-heat-for-cycling-and-walking/examples-of-applications-of-the-health-economic-assessment-tool-heat-for-walking-and-cycling [Accessed 22 April 2021]

WHO ( ) Health economic assessment tool (HEAT) for walking and for cycling. Available from: https://www.euro.who.int/__data/assets/pdf_file/0010/352963/Heat.pdf [Accessed 22 April 2021]

sweep

De Bell, S., Hind, K., Abrahams, R., Lovell, R.& Wheeler, B. (2021) *Evaluating interventions in green space: Derriford Community Park, Plymouth.* This SWEEP resource was produced as part of the Investing in Nature for Health project.

SWEEP is a partnership between the University of Exeter, the University of Plymouth and Plymouth Marine Laboratory.

Funded by NERC, it brings together experts and stakeholders to solve key challenges faced by those working with our natural resources.

European Centre for Environment & Human Health

NERC SCIENCE OF THE ENVIRONMENT

sweep
Investing in Nature for Health
RESOURCE

A Five Capitals Model approach

Building a business case for investment in nature for health

This report was produced in collaboration with our project partners

rspb giving nature a home | WWT Saving wetlands for wildlife & people | Dorset Local Nature Partnership | active CORNWALL | Cornwall Area of Outstanding Natural Beauty

This Resource

The need for a clear and robust business case framework to support investment in nature for health

There is evidence of a growing disconnect between people and nature, and simultaneously an increase in mental health disorders and physical health problems associated with insufficient exercise. There are opportunities to address these issues by capitalising on the *value* of nature for human health and wellbeing.

However, there is an urgent need for research not only to evidence these connections, but to help us understand *how* our natural resources can best be used, improved, and managed to deliver health benefits

Faced with an ever increasingly competitive funding environment, one of the keys to success will be using current evidence to develop more robust business cases that can attract greater investment into this area.

The purpose of this resource

This resource demonstrates how the Five Capitals Model approach, backed by relevant evidence, can provide a convincing and credible framework for strengthening such business cases, placing natural capital and human health benefits at the centre of interest.

Commonly, the emphasis has tended to focus more on financial, manufactured, social and human capital as these are most immediately obvious and intrinsically internal to decision-making processes.

Natural capital has typically been regarded as external to decision-making processes resulting in over exploitation and depletion. The use of the five capitals approach addresses this oversight by bringing all capitals onto an equal footing, clarifying the interdependencies between all five types of capital.

This resource emphasises how natural capital can be included by applying the five capitals approach, the benefits of doing this for human health and wellbeing, and to evidence how natural capital can underpin investment in the other four capitals.

As such, this document has the potential to be a valuable tool for stakeholders delivering nature-based health outcomes across a range of applications from strategic development thinking, resource planning, prioritisation and delivery of projects, monitoring and evaluation activities and outcomes and the development of funding proposals.

> *"SWEEP's evidenced based resources have informed and strengthened the drafting of Cornwall City Council's five year social prescribing strategy. This five capitals model approach resource has enabled me to illustrate how different elements of my work, that deliver health and wellbeing objectives, link together.*
> **Rich Sharpe, Public Health Specialist and Lead Mental Health and Suicide Prevention, Cornwall Council"**

For your use ...

We've specifically included the following elements in this resource to support your own work

- Descriptors of terms
- Visual diagrams (please always credit as outlined in footnotes)
- Case studies of where the five capitals approach has been applied in natural capital contexts
- Case studies that illustrate how each of the five capitals can be linked to health and wellbeing outcomes

What is the Five Capitals Model?

The Five Capitals Model was developed in 2018 by Jonathan Porritt, Co-Founder of Forum for the Future, to provide a basis for understanding sustainability in terms of the economic concept of wealth creation or 'capital'.

The model is based on five types of capital from which we derive the goods and services we need to improve the quality of our lives

Definitions of the Five Capitals [1]

Natural capital is any stock or flow of energy and matter that yields valuable goods and services. It includes resources, some renewable (timber, grain, fish and water), others not (fossil fuels); sinks which absorb, neutralise or recycle wastes; and processes, such as climate regulation.

Social capital concerns the institutions that help us maintain and develop human capital in partnership with others; e.g. families, communities, businesses, trade unions, schools, and voluntary organisations.

Human capital consists of our health, knowledge, skills and motivation, all of which are required for productive work. Enhancing human capital, for instance through investing in education and training, is vital for a flourishing economy.

Financial capital plays an important role in our economy, enabling the other types of capital to be owned and traded. Unlike the other capitals, it has no real value itself but is representative of natural, human, social or manufactured capital.

Manufactured capital comprises material goods or fixed assets - tools, machines, buildings and other forms of infrastructure - which contribute to the production process, but are not used up in it.

Good to note ...

- 'Capital is an asset that produces future benefits in the form of flow services. The five capital theory states that human wellbeing depends on service flows form five conceptualised stock categories, where financial capital is seen as a liquid asset to facilitate interchange between the other categories'. (Maack & Davidsdottir, 2015)

- The five capitals defined above have the following features:
  - They comprise the productive base of a body's economy and therefore, together, capture the overall wealth of that body
  - They require investment to remain productive over time
  - They are often partial complements and partial substitutes with one another (Davenport et al., 2019)

- All organisations use these capitals to different degrees to deliver their products and/or services. For an organisation to operate sustainably, it will maintain and, where possible, enhance these stocks of capital assets, rather than deplete or degrade them. The model enables businesses to consider a wide range of environmental and social issues that affect their practices, allowing all of these to be integrated in long-term sustainable financial planning.

[1] Adapted from https://www.the-ies.org/sites/default/files/reports/T%26A_Training_Manual.pdf and https://www.forumforthefuture.org/the-five-capitals

The Five Capitals Model

Figure 1 shows the five capitals that comprise the model and how they connect to a core organisational issue or aim.

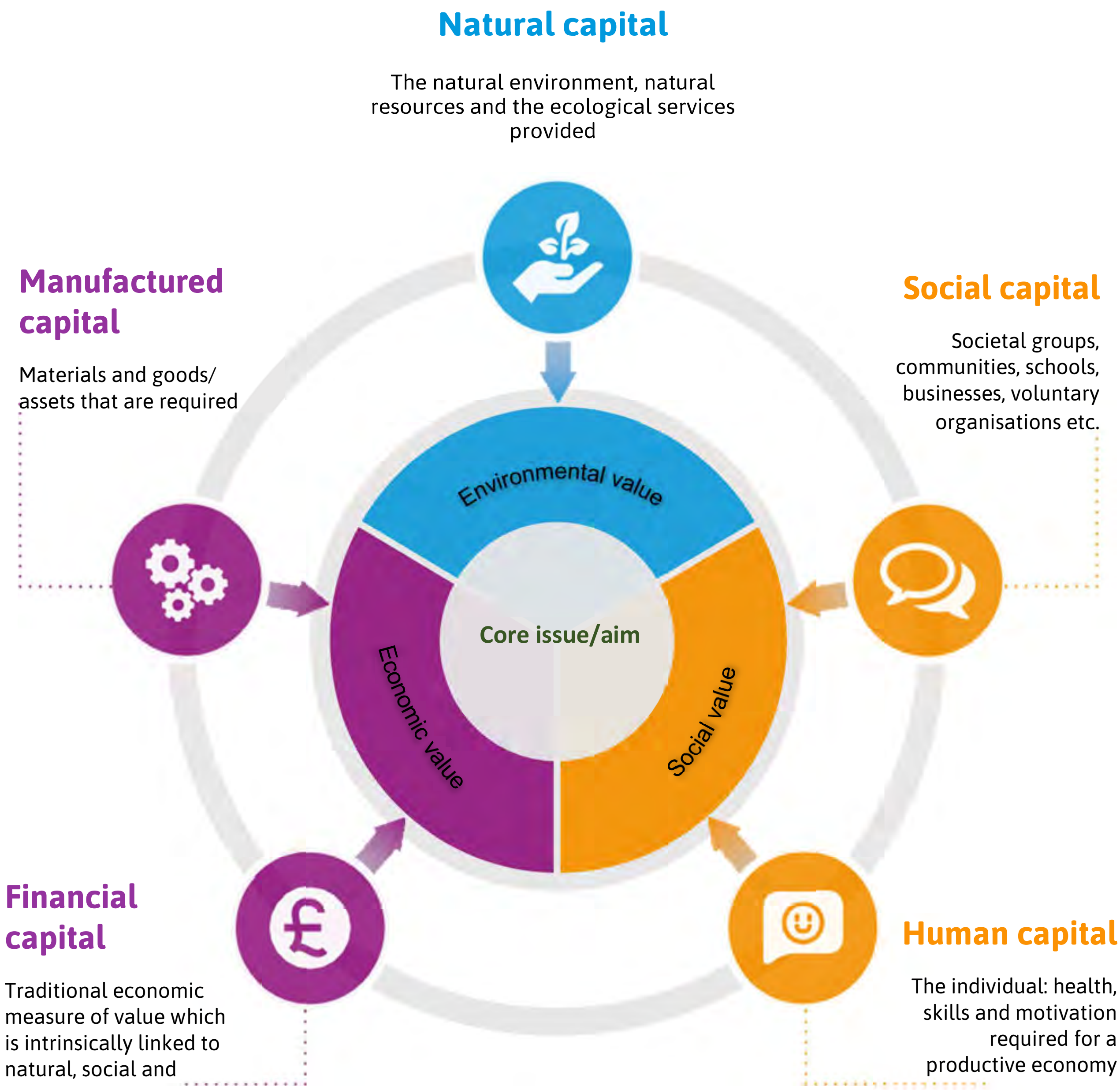


Figure 1: The five capitals model [2]

[2] Reproduced with kind permission from the Association for Consultancy and Engineering (ACE) https://www.acenet.co.uk/media/5151/ace-five-capitals-report-2020.pdf

How can we use the Five Capitals Model to strengthen cases for investment in nature for health?

The Five Capitals Model offers a robust conceptual framework that can be used to help identify and communicate (and potentially quantify) sustainable policies, strategies, plans, programmes and interventions that deliver human health benefits.

It offers a dynamic approach enabling organisations to think about how to achieve a balance between their environmental, social and economic activities. It encourages consideration of what an organisation needs to do to maximise the value of each capital whilst pursuing agreed priorities or objectives, as well as factoring in the impact of its activities on each of the capitals.

As such, we argue that the Five Capitals Model can be successfully applied to the development of business cases for investing in nature for human health outcomes. It provides a means of evidencing the role that health and wellbeing can play in contributing toward organisational priorities, placing natural capital at the centre of interest, while simultaneously adding value to the other capitals.

> *This resource instinctively feels like it has very broad application and relevance to today's climate.*
> **Alison Wills, Strategic Relationship Manager, Active Cornwall**

> *This model has been incredibly useful for our NLHF application and will surely be useful for future bids. Many of our projects explore the connection between nature and wellbeing, therefore I feel this to be a highly useful resource for organisations like ours.*
> **Jacob Parry, Cornwall AONB Unit**

Applying the Five Capitals Model

This approach can be used to support activities both at a strategic and project level, for example;

- Informing strategic organisational thinking about how best to invest across the capitals to achieve health and wellbeing goals
- Demonstrating how investment in different capitals by different organisations, at programme or project level, can be mapped against health and wellbeing outcomes to deliver multiple outcomes and benefits
- Planning more effectively for resource allocation across the different capitals
- Applying appropriate outcome and impact metrics to each capital to assist with monitoring, evaluation and reporting activities
- Communicating more clearly with funders and stakeholders about how a proposed programme of activity will deliver health outcomes, and integrate with existing organisational systems and structures

Taking a closer look -
Understanding the five capitals in relation to your organisation

Figure 2 presents some broad themes that might be considered within each capital

Figure 2: Themes within the five capitals [3]

SWEEP's five capitals model resource is a really useful resource and is helping to shape my thinking in relation to my work with Health and Nature Dorset (HAND). HAND aims to strengthen joint collaborative working on nature-based wellbeing between the health, environmental and business sectors to support population health, develop opportunities for prevention at scale and reduce health inequalities across Dorset.

Maria Clarke, Dorset Local Nature Partnership Manager

Building on this, further information is available in our [Supporting Document: A Five Capitals Model approach – Building a business case for investment in nature for health.]() Along with further case studies, you will find a series of tables and descriptions of the five capitals highlighting further examples of themes that relate to each capital, as well as the kind of business objectives these could inform. These examples are drawn from academic literature that highlight cases where the Five Capitals Model has been applied within real environmental contexts.

[3] Reproduced with kind permission from the Association for Consultancy and Engineering (ACE) https://www.acenet.co.uk/media/5151/ace-five-capitals-report-2020.pdf

Adapting the Five Capitals Model to health and wellbeing outcomes

There are a number of evidence-based case studies that help us understand how investment in each of five capitals (or combinations of capitals), where underpinned by natural capital (through the provision of natural assets), can result in improved human health and wellbeing. Examples of these are outlined below and help to illustrate how developing activities, interventions or programmes which draw on all the capitals are most likely to be successful, delivering multiple benefits for an organisation.

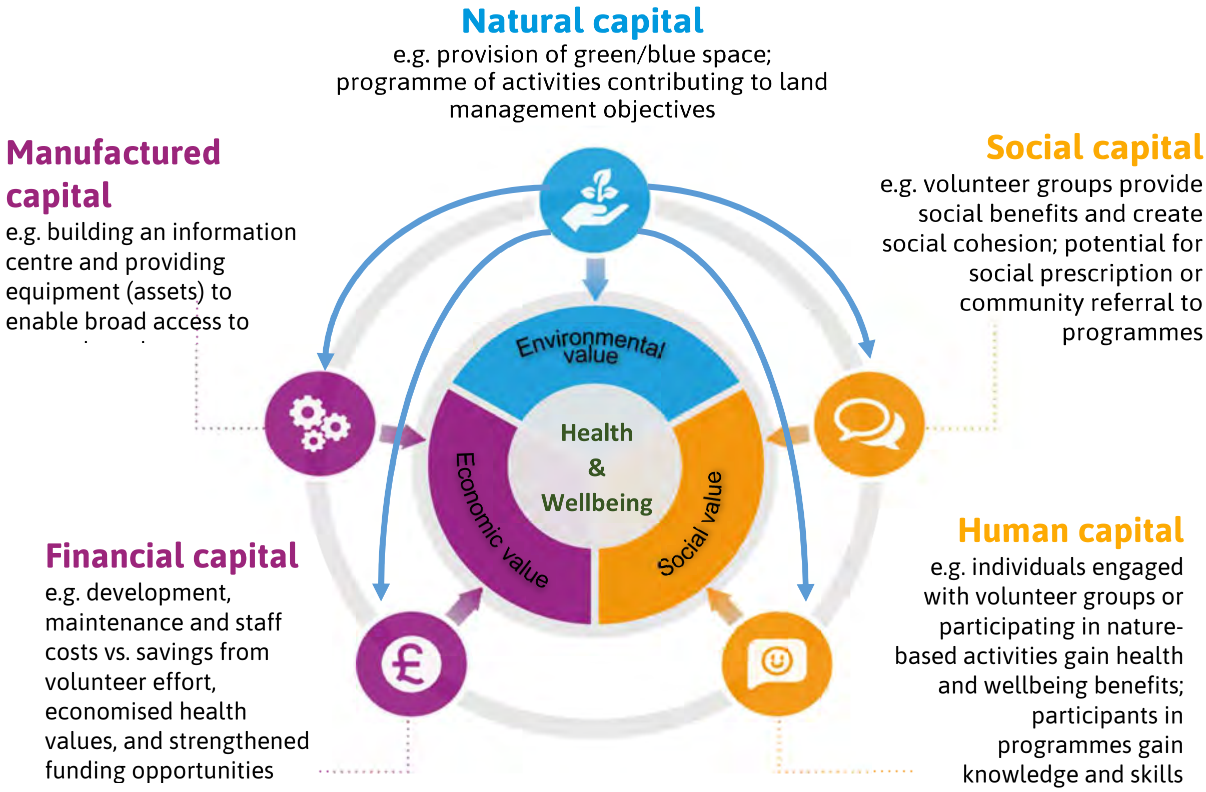


Figure 3:
Adaptation of the Five Capitals Model to illustrate a conceptual holistic application to health and wellbeing outcomes [4]

Figure 3 above represents a conceptual illustration of this, demonstrating how the Five Capitals Model could be used as a visual tool to communicate with key stakeholders. This example is based on a nature reserve's objective to enhance both natural capital and health and wellbeing outcomes both through the development of an information centre that acts as a hub to attract visitors, and the provision of a programme of nature-based activities and land management operations that enrich the local natural capital.

The diagram helps to communicate the connection between each capital, with improved human health and wellbeing sitting as the central aim. It also illustrates how natural capital should be viewed as central to sustainable decision making, underpinning the other capitals through its provision of valuable goods and services on which they depend. While each of the capitals should be enhanced over time to ensure a successful and sustainable operation, an emphasis on investment in natural capital can provide the critical foundation to support the other capitals, and deliver human health benefits.

This is not an exhaustive diagram, and could be further annotated to suit individual needs. For example, specific health and wellbeing outcomes could be added in the centre in relation to planned interventions, along with appropriate measures to monitor and evaluate the success of health and wellbeing outcomes and impact.

[4] Adapted from original diagram with kind permission from the Association for Consultancy and Engineering (ACE) https://www.acenet.co.uk/media/5151/ace-five-capitals-report-2020.pdf

Case Studies

Evidence-based case studies demonstrate the value of health and wellbeing outcomes for each of the five capitals and can be used, alongside the Five Capitals Model, to strengthen cases for investment in nature for health. Further case studies are available on the SWEEP website, *Supporting Document: A Five Capitals Model approach – Building a business case for investment in nature for health.*

Case Studies A

This first set of case studies (A) illustrates how the five capitals model approach has been **applied** to natural capital focused projects enabling better planning, communication and delivery of both overall, and specific health and wellbeing objectives.

A1 | Sustainability appraisals

A SWEEP project team (Hooper & Austen, 2020) developed a natural capital framework that can be applied to sustainability appraisals. A scoping phase starts the process using a broader five capitals model. With stakeholder input, and following identification and review of relevant programmes, policies and plans, the overarching aims and related objectives, indicators and targets can be broken down into constituent parts that encompass the environment, infrastructure, individuals, and wider society.

The natural capital framework proposed by the authors draws from the environmental inputs to the wider Five Capitals Model (natural capital and some elements of manufactured capital). For the natural capital element, baseline information consists of four core elements: an asset register (in which information on the status of natural capital is compiled), an ecosystem services inventory (to list services, benefits and values); an asset-service matrix (to connect services to the assets from which they are derived); and a risk register (which summarises threats to continued system functioning).

This scoping process provides a comprehensive and systematic baseline of the current status and trends in assets, services and benefits, and the degree to which they are at risk, allowing for the selection of detailed and meaningful sustainability objectives and indicators. The authors argue that this approach supports better outcomes than using high-level objectives and indicators such as the number and condition of protected sites.

The Five Capitals model is already widely used in sustainable development contexts, including in local planning; for example, by Powys County Council (2017), and Calne Town Council (2012).

A2 | Environmental investment assessment options

Yorkshire Water (YW) conducted a Five Capitals Assessment of its Little Don Recreation Plan which aimed to promote health, fitness, and wellbeing through inclusive and accessible outdoor recreation opportunities (reaching out to groups not commonly represented by visitor surveys) (Yorkshire Water, 2018). The Little Don Recreation Plan attempted to develop opportunities for innovative ideas and solutions that would benefit the natural environment and the local and wider community.

With consultants, YW developed a replicable approach via a quantitative tool that could be used to compare a wide range of project design options, based on the five capitals, providing a shortlist of five scenarios for site development.

The process started with a baseline assessment of the study area (three reservoirs and associated habitats), including assessments of natural capital assets, ecosystem service provision, socio-economic data, and qualitative descriptions of the activities that contribute to the human and social capital (i.e. employment, skills, health & safety, wellbeing, quality of place, and trust).

The second stage was to conduct an option prioritisation exercise which compared a longlist of potential options for the Little Don site against a range of qualitative scoring criteria, the scores being determined by the impacts of each activity on the five capitals. Five broad options resulted - woodland creation, moorland restoration, artificial beach with play area, dark skies observation centre, and water sports activities.

However, YW found limitations with this exercise and opted instead to develop a quantitative tool that could be used on the full range of options to support robust comparisons of each option's strengths and weaknesses, with a focus on health and wellbeing and economic impacts. The 'Capitals Valuation Tool v1.0' aimed to allow users to compare a wide range of land management options across the capitals at the Little Don site as well as at other sites owned by Yorkshire Water. A pilot exercise applied the tool to five possible scenarios for development: Inclusive Environment; Active Recreation; Active Biodiversity; Sustainable Farming; and Sustainable Forestry.

The impacts of the scenarios were calculated over a 40 year assessment period, with the results compared against the baselines for each option. Facilitating active recreation on site was shown to have the greatest potential positive impact of the five scenarios, despite the highest costs. The pros and cons of each of the options for the Little Don site were demonstrated, and it was suggested that there can be important trade-offs between goals of encouraging visitor diversity, protecting biodiversity, and creating employment opportunities.

The health and wellbeing elements are reflected by the outdoor recreation and exercise values within Social Capital (presumably emphasising physical health).

YW concluded that there were many potential uses for this tool, including high level optioneering for informing land management decisions, communicating results, complementing broader organisational decision-making frameworks, and for 'Net Gain' (informing the approach to biodiversity offsetting and design of capital delivery schemes).

Note

A detailed methodology showing all the five capital elements factored in by the tool are shown as an appendix to the final project report.

https://www.yorkshirewater.com/media/dgcbfpdl/report.pdf

A3 | Managing Resilience

Resilience has become a priority consideration for water companies, with significant challenges arising from, for example, increasing customer demand for better services, and the need to demonstrate stability to investors. OFWAT made resilience one of its four key themes in its 2019 Price Review, putting water companies' approaches to managing resilience under the spotlight, and making it clear that investment returns should be generated from the provision of good customer and wider society services (rather than from spend on built assets alone). Sustainable financing and long-term resilience could be achieved by tapping into natural, social and human capital, as well as financial and built capital.

AECOM (Rowcroft, 2020) describe how the five capitals model can be applied to tackle the risks of a) too much water and b) too little water. For example, they suggest how investment in sustainable drainage measures, such as creation of wetlands and green verges in urban areas (utilising natural capital) provides wider benefits than flood prevention i.e. improved air and water quality, and enhanced local wellbeing and amenity through the creation of green spaces (human and social capital). Water companies such as United Utilities and South West Water, rather than imposing water use restrictions during times of drought and high water demand, have instead allocated land in upper catchment areas to act as natural reservoirs, soaking up and storing rainwater naturally and allowing gradual release downstream, so avoiding peaks and troughs in water supplies. This approach leads to wider natural, social and human capital benefits such as increased biodiversity and the creation of space for recreation and learning, as well as improving the quality of water provided to customers, saving company money, and reducing carbon footprints. Water companies can also use education campaigns — a good example of social capital— to encourage customers to use water more responsibly.

AECOM purports that holistically embedding all five capital values in business decision making and investment planning will enable water companies to give greater assurance to investors and regulators that their service delivery and financial performance is resilient and sustainable, so attracting further investment.

Case Studies B

This second set of case studies illustrates how each of the five capitals can be **linked** to health and wellbeing outcomes.

Further case studies are available on the SWEEP website in our *Supporting Document: A Five Capitals Model approach – Building a business case for investment in nature for health*.

Natural Capital Case Studies

Green space quality enhancements, improving wellbeing

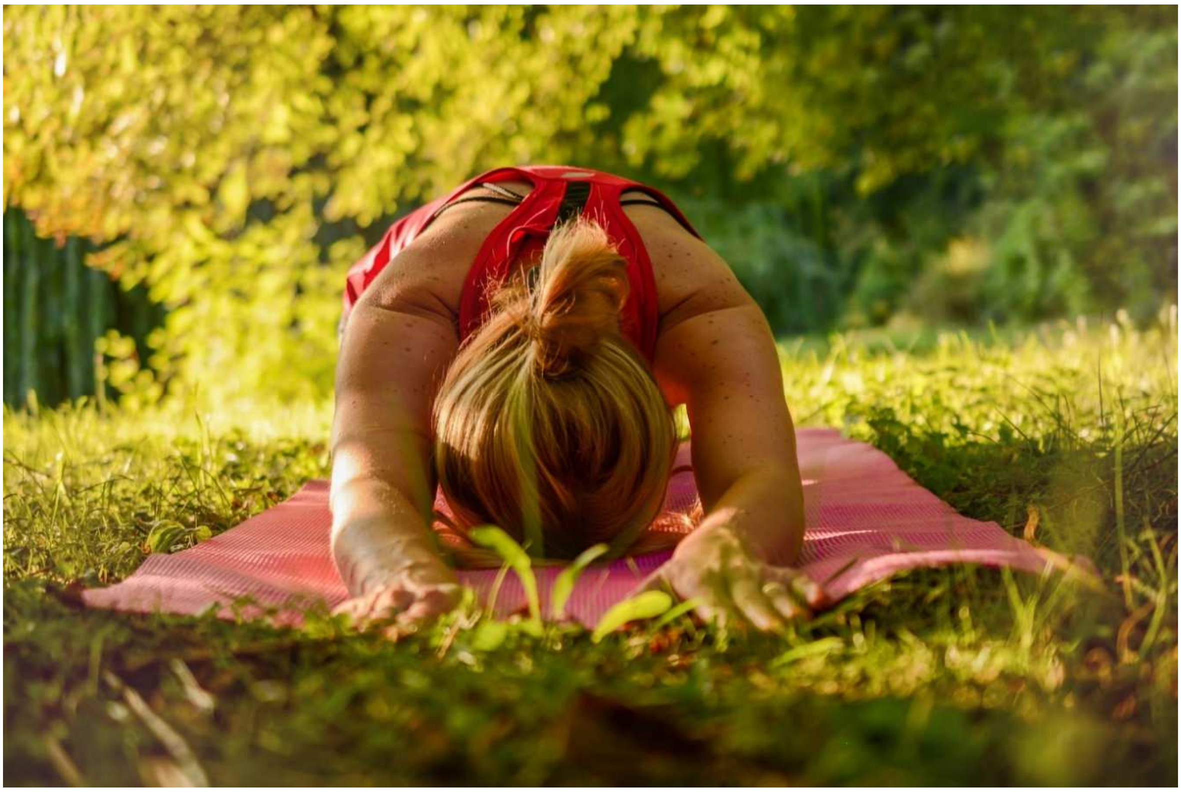
B1 | Visits to natural spaces and psychological restoration

Summary: White et al. (2013) analysed Monitor of Engagement with the Natural Environment (MENE) 2009-11 survey data, which categorized England visit destinations into types of natural environments, in broad themes including: a) parks and open spaces in towns and cities, b) the countryside, c) seaside resorts and towns and d) open coastline, including beaches and cliffs, and sub-categories (e.g., playing fields, allotments, farmland, woodland, country parks, rivers). The authors were able to compare feelings of restoration associated with visits of 4255 participants to different natural environments.

Metric: They created a variable, "recalled restoration" by collapsing two survey items in which respondents agreed that their visit "made me feel calm and relaxed" and "made me feel refreshed and revitalised". Multiple regressions were used to investigate the relationship between the type of environment visited and recalled restoration.

Results: Feelings of restoration following visits to any natural space were found to be high overall, reflecting the restorative effects of natural environments in general. However, restoration was found to be significantly higher for visits to hills/moors/mountains, woodlands/forests, beaches and 'other coast habitats' than, for example, urban green spaces (such as playing fields).

Application of findings: These findings help improve understanding of which environments people find most restorative and, therefore, which natural capital assets could benefit from investment to, for example, improve access or increase protection and condition.



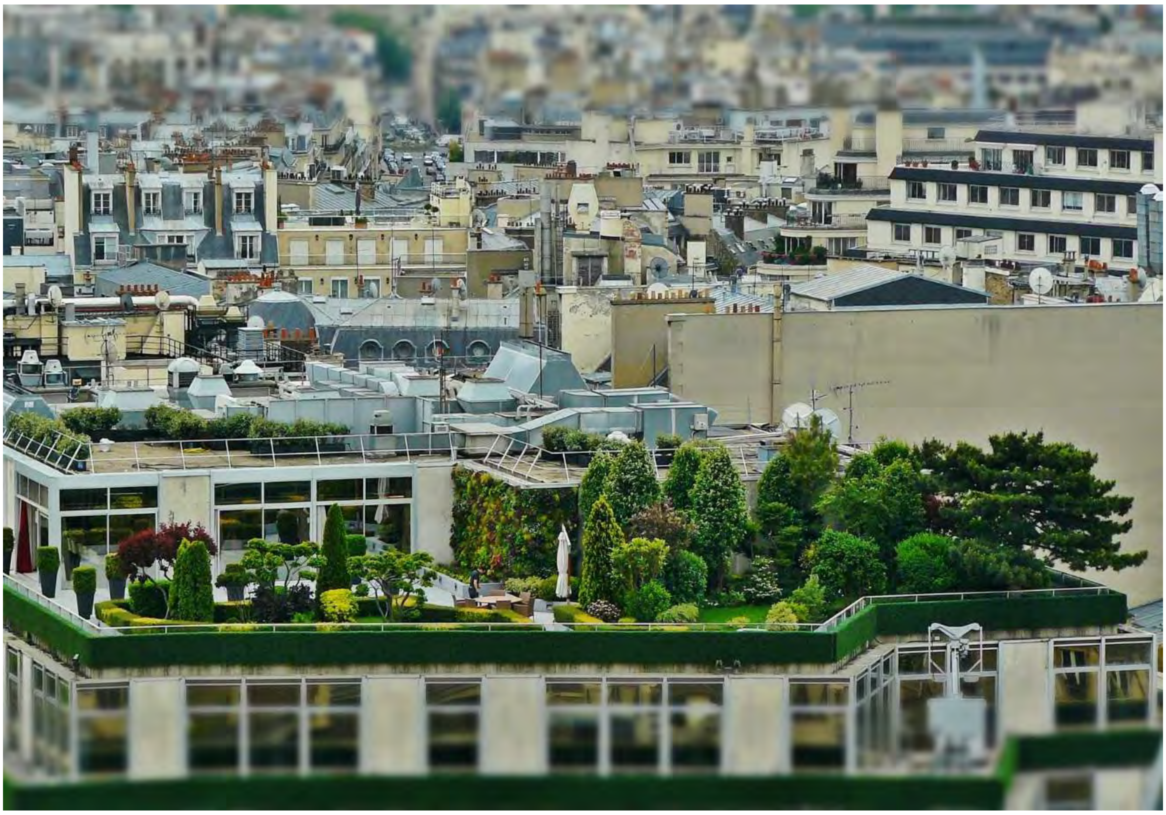
B2 | Different types of well-being experience associated with nature engagement

Summary: Bell et al. (2018) adopted a three-stage, qualitative, interpretive study which sought to understand and situate people's natural environment well-being experiences within their everyday lives. Thirty-three participants carried an accelerometer (measuring physical activity) and a Global Positioning System (GPS), (measuring location) receiver for one week while spending time in various green/blue spaces, the resulting data being used to produce a set of personalised activity maps showing where the participants went each day of that week and how long they stayed in different places. The maps were used as visual prompts to guide an in-depth geo-narrative interview exploring how and why they engaged with different local environments for well-being, and how they felt this had changed over time. In-situ interviews were also held with a subset to further capture place experiences.

Metric: A narrative thematic analysis was used to identify patterns and themes recurring across participant accounts to understand variations in well-being experiences.

Results: Four types of routine natural environment encounters emerged, 1. Social - for example, shared wildlife encounters by family units, and intergenerational interactions; 2. Immersive - restorative power of wildlife engagement, sense of awe-and-wonder, and escape from the everyday; 3. Symbolic - feelings of freedom and a sense of perspective through consciously connecting with wildlife, sense of comfort during periods of depression, and importance of observing and connecting to wildlife life cycles; and 4. Achievement – for example, fishing, wildlife spotting and species identification.

Application of findings: Recognition by green space and health professionals of mutual environmental and well-being benefits could enable informed investment in green space design and management approaches that create socially inclusive opportunities for diverse well-being experiences whilst also promoting the ecological value of such spaces.



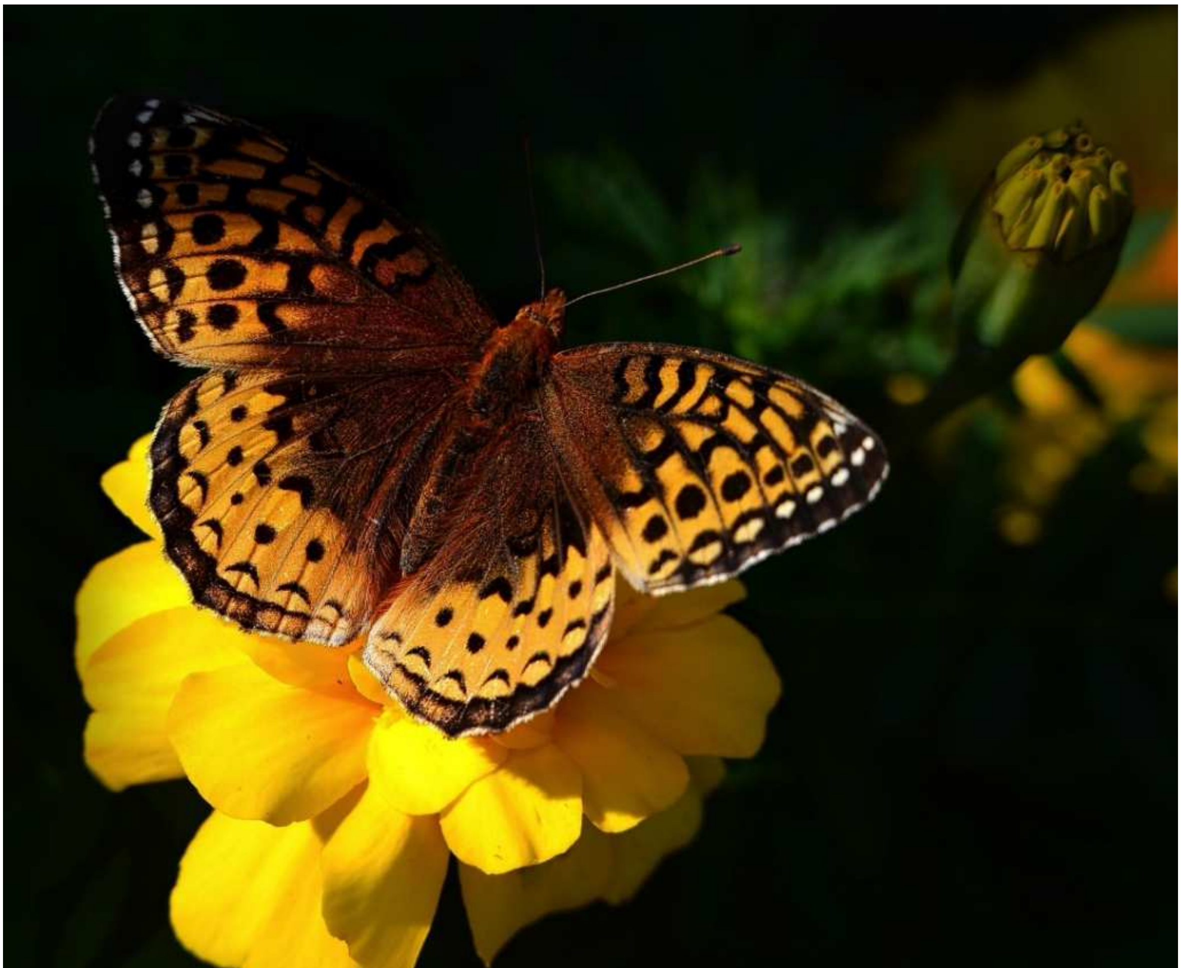
B3 | The relationship between nature connectedness and environmental quality

Summary: Wyles et al. (2019) used data from a large England MENE survey to determine the roles that type and quality of natural environments have on an individual's sense of connectedness to nature, and psychological restoration. Using a sub-sample of 4,515 people who described and evaluated a visit within seven days of completing the survey.

Metric: Three main environmental types were generated from survey questions: Urban green, rural green, and coastal. Environmental quality of the visit location was based upon official designated status including: National Parks, Sites of Special Scientific Interest, National or Local Nature Reserves and Areas of Outstanding Natural Beauty. A set of visit characteristics was established i.e. duration of visit, nature of activity, distance travelled to site, and size of group. 'Recalled connectedness to nature' and 'recalled restoration' were operationalised measures derived from specific survey questions.

Results: Respondents recalled greater connectedness to nature and restoration following visits to rural and coastal locations compared with urban green space, and to sites of higher environmental quality (for example, nature reserves).

Application of findings: These findings are potentially relevant for the management of natural environments. The combination of different effects of particular types of nature with designated areas being associated with greater psychological benefits (RCN and RR), reinforces the need for land managers to avoid oversimplifying natural environments. The findings evidence an association between psychological benefits and visits to different types of natural settings, irrespective of socioeconomic status. This highlights the importance of prioritizing access to and protection of different environments.



Manufactured Capital Case Studies

Green space and infrastructure co-developments plus other added benefits for integrating investment in natural and material assets

B4 | Investment in physical assets contributes ultimately to nature-based health benefits

Summary: Hampshire County Council commissioned a community engagement strategy to develop a new visitor hub at Lepe Country Park, a coastal site within the New Forest National Park. The enhancements included construction of a new visitor centre, restaurant, sensory cottage garden, play park, improved paths, security measures, parking and toilet facilities, with a particular focus on improving access for people with disabilities. The driver for this transformation programme was to attract more visitors, and for visitors to stay longer at the park, by providing new modern facilities that enhance visitor enjoyment. Proceeds from the facilities are ploughed back into maintenance of the wider park environment, so moving it toward becoming financially self-sustaining, and providing benefits to people in the long term (Green Halo Partnership, 2021).

Metric: Number of park visitors; compliance with parking requirements and honesty boxes (financial measure).

Results: This project used external funding to create new, and improve existing, assets. These changes will draw in more visitors to enjoy the country park's green and blue features (natural capital), so providing health and wellbeing being benefits for more people over a sustained period of time.

Application of findings: This initiative demonstrates how a multi-capital approach can be used for problem-solving (in this case, how to improve Lepe County Park's long-term sustainability).

B5 | Integrated grey and green regeneration for multiple health gains

Summary: Dallat et al. (2013) estimated the potential health impacts and cost-effectiveness of an urban regeneration project in Northern Ireland, the Connswater Community Greenway, offering new cycle- and walk-ways and providing accessible and safe green space. Before and after surveys of the Greenway community included the Global Physical Activity Questionnaire, used to determine the number of minutes of physical activity performed per week per interviewee. From this, the proportion of those meeting the current physical activity recommendations of 150 minutes per week of moderate physical activity were calculated. Other data sources included population data derived from NISRA, population disability weights using UK EQ-5D data, disease data from NICR, and NI Health & social wellbeing survey, GP and research database. Also disease weight data from Global Burden of Disease study. The PREVENT model was used to compare projected future disease with and without the intervention and calculated the gains in life expectancy (LE) and disability-adjusted life expectancy (DALE) expected for intervention beneficiaries and the years lived with disability (YLD) saved by the Greenway population.

Metric: Macro-simulation PREVENT model used to model the project's potential impact on the burden from cardiovascular disease, type2 diabetes mellitus and stroke, and colon and breast cancer, by the year 2050.

Results: The aim was to present the incremental cost-effectiveness ratios (ICERs) of the Greenway intervention. The authors calculated costs saved through diseases averted and summed all diseases to get total disease cost savings; health outcomes were derived in DALYs. If 10% of 'inactive' people became 'active', 886 incident cases (1.2%) and 75 deaths (0.9%) could be prevented with an incremental cost-effectiveness ratio of £4469/DALY (below the UK cost-effectiveness threshold of £20 000–£30 000/QALY or DALY). At 2% effectiveness, the intervention would remain cost-effective (£18411/DALY). Small gains in average life expectancy and disability-adjusted life expectancy could be achieved, and the Greenway population would benefit from 46 less years lived with disability.

Application of findings: Demonstrates the potential economic benefits (financial capital) of combining investment in enhancements to manufactured capital (cycle tracks and pathways), and natural capital (green spaces), and generating human capital outcomes (individual health gains). Of interest to urban regeneration project planners; and funders of such projects. Public health professional may be interested in potential scaling up of health benefits derived from such projects.

B6 | Urban Green Blue Infrastructure design can benefit users' mental health

Summary: Andreucci et al (2019) examine the current status of 'mental health-sensitive' open space design in the built environment. Urban Green Blue Infrastructure (UGBI) can contribute to urban dwellers' mental health and wellbeing as well as healthy aging, while providing co-benefits balancing the negative impacts of climate change, through the provision of integrated ecosystem services. The authors argue that there is a paucity of evidence of the actual benefits achieved by exposure to, and affiliation with, nature, as well as the key performance indicators and metrics to monitor and adapt open spaces to key urban challenges. Concepts of increasing degenerative mental disorders in urban environments are described, as is the emerging green blue infrastructure design approach. UGBI is normally a hybrid infrastructure of green or blue spaces, and built systems. Examples are urban forests, parks, domestic gardens, green roofs and walls, and community orchards, while blue components might feature wetlands, rivers, canals, ponds, and streams.

Metric: Comparative critical analysis

Results: International case studies describe how evidence-based design and Nature-based Solutions have been found to be beneficial for supporting healthy aging through exposure to, and affiliation with, biodiversity, and especially to those diagnosed with mental disorders and dementia; for example, landscape architects designing therapeutic or healing gardens, promotion of edible cities, and dementia-friendly communities such as The Village in Canada, and Hogeweyk in the Netherlands which strongly emphasise integration of green/blue spaces into urban design.

Application of findings: The multiple benefits evidenced by these UGBI case studies for people's health, particularly mental health and dementia, should interest and influence landscape planners and designers. The actual benefits of designed garden spaces for people with dementia are still not fully supported by meta-analyses and should be the subject of further research.

B7 | Engaging with diverse natures can provide opportunities for shared sociality

Summary: Bell et al. (2019) draw from post humanist theories of social practice to identify or prescribe a standardised healthy nature interaction. Relational understandings of interactions with nature move beyond static notions of bounded spaces (i.e. a park, a woodland etc) where a person simply has to visit to gain health or well-being benefits. Rather, social practice encourages engagement with the "transformative potential of the entire field of relations with which beings of all kinds interact". Two social practices - beach-going and citizen science— demonstrate how a focus on social practices can better cater for the diverse and dynamic ways in which people come to conceptualise, embody, and interpret nature in their everyday lives.

Metric: Critical analysis based on author experience of several research projects

Results: Engaging with diverse natures can provide opportunities for 'shared sociality', which may be between friends, family, fellow wildlife enthusiasts or professionals. Such experiences can build strength, skill, and confidence to engage with one another and to nature.

Application of findings: The authors advise caution against universal prescriptions of nature doses across populations without engaging with people's unique and relational embodied priorities. Those with responsibility for enabling people to connect with nature, such as environmental land managers, conservation charities, urban planners, and landscape architects, should make the effort to understand how best to accommodate diverse sensory, physical, and psychological needs within site management, visitor experiences, and community engagement.

B8 | Community gardens foster social cohesion and improve wellbeing

Summary: The Women's Environmental Network (WEN) was commissioned by London Borough of Tower Hamlets' (LBTH) Public Health department to help set up 15 community gardens across the Borough. This 15 month project (April 2014 – July 2015) was designed to help improve residents' wellbeing by providing increased access to healthier food and creating community cohesion by working together, with support from WEN's community garden coordinators, to develop the growing spaces. Fifteen community gardens were successfully set up using two gardening coordinators who engaged 4,485 Tower Hamlets residents. 178 residents actively participated in gardening, largely growing food, and were supported by training sessions covering practical and theoretical topics of site planning, garden design, organic food growing, healthy eating and cooking, tailoring each workshop to the needs of the group. Within this programme, the Tower Hamlet Food Growing Network provided access to a community seed library, to which users 'borrowed' seeds at the start of the growing season and 'returned' seed from their crops in the autumn. This project was designed to help improve residents' wellbeing by providing increased access to healthier food and creating community cohesion by working together (Pinto, 2017).

Metric: Measure of wellbeing; qualitative feedback from participants and volunteers.

Results: The Gardens for Life project showed an improvement in wellbeing for over half (59%) of participants for whom data were available (12.5%); new opportunities were provided for people to meet their neighbours and build a sense of community around the garden itself; the project successfully promoted all of the 5 ways to Wellbeing ; including Connect, Be Active, Take Notice, Keep Learning and Give, through the acts of learning new skills, sharing their produce with friends and family and increasing their levels of physical activity; the project provides access to local food and encourages healthy eating; individual feedback highlighted a host of community benefits and how the gardens helped build social capital.

Application of findings: This project demonstrates the health and social benefits of a community garden programme. There are added sustainability benefits of linking activity-based programmes with existing networks, which can provide support, advice, networking opportunities with other communities, access to related schemes and facilities.

B9 | People in connector roles are key actors for developing social capital

Summary: Tierney et al (2020) examined connector schemes (e.g. delivered by care navigators or link workers) that have become a key component to the successful delivery of social prescribing services. People in these connector roles support patients by either (a) signposting them to relevant local assets (e.g. groups, organisations, charities, activities, events) or (b) taking time to assist them in identifying and prioritising their 'non-medical' needs and connecting them to relevant local assets. A review was undertaken to better understand how such connector schemes work, for whom, why and in what circumstances.

Metric: Realist review

Results: Context- mechanism-outcome configurations (CMOCs) reinforced the authors' developing theory that centred on the essential role of 'buy-in' (of stakeholders e.g. patients, GPs, commissioners, primary care staff) and connections (strong, ongoing interrelations). This was refined further by turning to existing theories on (a) social capital i.e. bonding between link worker and patient, and bridging between patient and services, and (b) patient activation i.e. matching interventions to patient's ability to manage their health.

Application of findings: Connector roles, especially link workers, represent a vehicle for accruing social capital (e.g. trust, sense of belonging, practical support). This affords patients with the confidence, motivation, connections, knowledge and skills to manage their own well-being (patient activation), hence reducing reliance on GPs. Patient activation is identified by NHS England as a key measure for assessing link worker services within primary care networks.

Human Capital Case Studies

Individual physical or mental health gains

B10 | Walking in quality green/blue spaces improves self-esteem and mood

Summary: Barton, Hine & Pretty (2009) evaluated changes in self- esteem and mood of participants walking in four different National Trust sites of natural and heritage value in the East of England, including forests, fens, lowland heaths and coastal areas. The self-esteem and mood of a proportion of the visitors at the four sites was measured pre- and post-activity. The study assessed changes in psychological health parameters, using standardised internationally recognised scales, following a single visit to a greenspace of natural and heritage value.

Metrics: The Rosenberg Self-Esteem Scale (RSE) a tool widely used in health psychology, was used to assess visitors' self-esteem. The authors also measured mood change pre- and post-activity using the Profile of Mood States test (POMS) which has previously been used to determine mood change post-exercise. A Total Mood Disturbance (TMD) Score was calculated to assess overall emotional state and the relationship between the duration of the visitors stay and the reported TMD scores when leaving the sites was investigated using statistical parametric tests.

Results: Self- esteem scores for visitors leaving the sites were significantly higher than those just arriving and overall mood also significantly improved. Feelings of anger, depression, tension and confusion were all significantly reduced and vigour increased.

Application of findings: The environment plays an important role in facilitating physical activities and helping to address sedentary behaviours. Walking, in particular, can serve many purposes including exercise, recreation, travel, companionship, relaxation and restoration. Walking in greenspaces may offer a more sustainable behaviour-change option, as it can enhance emotional wellbeing through both exposure to nature and participation in exercise.

B11 | Animal care increases self-efficacy and quality of life

Summary: In a Norwegian study, Berget et al. (2008) analysed video recordings to study the interactions between severely ill psychiatric patients and farm animals. Using a three-month intervention, mainly with dairy cattle, the authors examined the intensity and exactness of the patients' work with the animals. They investigated whether the working abilities were correlated with better self-esteem, coping ability, quality of life, or less depression or anxiety. The patients visited the farm for three hours twice a week for 12 weeks to participate in routine work with farm animals.

Metric: Several metrics were used, including the Spielberger State Anxiety Inventory (STAI) and the Beck Depression Inventory. Self-esteem was measured with the Generalized Self-Efficacy Scale (GSE); Coping was measured using the Coping Strategies Scale of the Pressure Management Indicator and a Norwegian version of Quality of Life Scale (QOLS-N) was used comprising 16 items and reflecting relations to other humans, work, and leisure.

Results: Psychiatric patients working with farm animals during the intervention increased both the intensity and the exactness in their work with the animals. Patients also showed increased self-efficacy and quality of life compared with the control groups, when measured six months after end of intervention.

Application of findings: Skills can be enhanced though working with farm animals which may be related to improved mental health exemplified by decreased anxiety or increased self-efficacy.

B12 | Therapeutic gardening improves mental wellbeing and confidence

Summary: Howarth et al (2020) examined a case study based on research with the RHS Wellbeing Garden Bridgewater (https://www.rhs.org.uk/gardens/bridgewater/Articles/helping-people-to-better-health). In a pilot study, people were referred to the Wellbeing garden through 'social prescribing' by health workers to reduce anxiety, develop confidence and/or mental wellbeing. The wellbeing programme is now looking at ways therapeutic gardening, gardens and green spaces can transform people's lives.

Metric: The Warwick-Edinburgh Mental Well-being Scale (SWEMWBS) was used to monitor mental well-being and focus groups were used to provide qualitative feedback.

Results: Participants who carried out gardening activities had improved mental wellbeing scores, improved confidence and reduced social isolation, and they highlighted an overall positive impact of the experience.

Application of findings: The findings from the SWEMWBS data provided evidence for continuation of a nature-based social prescription programme at RHS Bridgewater and represents an example of how nature-based interventions can be used by health workers to combat anxiety and support resilience.

Financial Capital Case Studies

Investment in nature-based solutions providing economic, health and well-being benefits

B13 | Method of calculating values of woodland sites and associated activities

Summary: Moseley et al. (2018) developed an indicator for woodland recreation that can help woodland managers to quantify the health benefits of recreational activities undertaken in their woodlands to inform local scale planning. They developed a quantitative physical recreation indicator using a step process. Firstly, they determined a non-financial estimate of annual calorific expenditure (ACE) based on a quality of experience survey that consisted of a standard set of questions for participants, accompanied by a measure of intensity of activities in calories and METs (Metabolic Equivalence of Task), where one MET is the energy equivalent to an individual seated at rest. Secondly, they placed a financial estimate on the annual physical health benefits. Quantification of benefits focussed on the physical energy expenditure of woodland recreationists through the calculation of the calories and METs used, followed by a calculation of Quality Adjusted Life Years (QALYs) from the METs and a monetary estimate of these values

Metrics: Annual calorific expenditure (ACE); Metabolic Equivalence of Task (MET); QALY

Results:

- QALY calculation = 30 min of moderate-intensity physical activity undertaken each week over one year would result in an additional 0.010677 QALYs per individual, per year for the general adult population. For each individual the QALY calculation is 0.010677 x M (duration)/30x F(frequency)/52. Median values for QALYS ranged from 0.001 to 0.015 across all the sites, with a maximum of 0.427. Total QALYs ranged from 0.129 to 3.542 depending on site. To calculate economic value, the authors used 1 QALY = £20,000 after White et al. (2016).

- The QALY monetary estimates for individuals that undertook a single activity for at least 30 minutes during their visit ranged from £6 to £8542. Median values ranged from £21 to £296, whilst total estimated values for the surveyed respondents per site ranged from £2581 to £70,832 (total no. of respondents = 2659). The authors were then able to scale these figures up to give a value for each woodland site, and for all sites combined**.**

Application of findings: The authors believe this method provides woodland (and therefore other habitat) programme managers, finance managers, and funders, a good alternative to, for example, the travel-cost method, particularly for small sites that offer informal recreation opportunities that can be particularly important for members of the public who may dislike or cannot afford formal exercise classes.

B14 | A health and wellbeing valuation of the South West Coast Path

Summary: Petersen (2020) provides a health and wellbeing valuation of the South West Coast Path (SWCP) based on available visitor and population data on visits to the trail. The author drew from a range of data sources - visitor data; online survey; data from the England Coast Path baseline assessment; selected data from an earlier SWCP coastal visits survey; data held by the SWCPA and Active Devon on their Connecting Actively to Nature (CAN) programme; and weighted MENE data.

Metrics: WHO HEAT tool, QALYs, UEA MOVES tool

- HEAT – calculates the reduced death rate using the statistical value of a life;
- QALYs – calculates the value of the additional years lived, as a result of improvements in health and reduced incidence of disease, adjusting this value for the quality of life;
- MOVES – calculates the savings in health care costs based on the reduced incidence of disease among walkers compared to non-walkers, converting this into savings to the NHS as a result of reduced treatment costs (and also reports results using QALYs).

Results: The valuation measures the estimated economic value of the physical health benefits from walking on the South West Coast Path. HEAT - Value of reduced death rate = £5.5M directly attributable, £69.1M in total; MOVES - savings in health care costs = 7.4M per year (value of QALYs gained). The MOVES valuation is in addition to the HEAT valuation, because it is based on the reduced occurrence of disease. .

Application of findings: Potential users of metric: SWCP and other site-based land managers and trustees; Social Prescription scheme coordinators and link workers for potential prescription options; public health authorities.

B15 | Social Return on Investment value of a nature-based volunteering programme

Summary: Bagnall et al. (2019) undertook a Social Return on Investment (SROI) analysis of the findings of a report in 2017 that investigated the changes in the attitudes, perceptions and mental wellbeing of Wildlife Trust volunteers taking part in nature conservation volunteering activities over a 12-week period. Six steps for an evaluation SROI were used – i/ establish scope; ii/ map outcomes; iii/ evidence and monetise outcomes; iv/ establish impact, v/ calculate SROI; vi/ and report use and embed results. Financial proxies for social values (WEMWBS, good overall health, nature relatedness, level of physical activity, volunteer time) were found using the global value exchange tool, the social value calculator, and a spreadsheet resource from the Greenspace Scotland SROI review

Metrics: Social Return on Investment value

Results: A SROI value of £6.88 for every £1 invested, for people with low wellbeing at baseline, who were part of a targeted programme; a SROI value of £8.50 for every £1 invested, for people with average to high wellbeing at baseline, who were part of a nature conservation volunteering programme. The SROI ratios calculated for this report were in line with calculations from a number of other programmes. For example, Greenspace Scotland applied an SROI analysis to the outcomes of a number of health-related interventions, including the value of conservation volunteers in delivering the Greenlink project, which was estimated to have resulted in a social return of £7.63 for every £1 invested.

Application of findings: NHS leaders will be interested in a mechanism that helps to identify reductions to the current burden on the National Health Service; GPs, mental health providers and Social Prescription service coordinators will be interested in a mechanism that helps to strengthen the argument for targeted green interventions to become standard practice.

Further case studies are available on the SWEEP website in our *Supporting Document: A Five Capitals Model approach – Building a business case for investment in nature for health.*

References

ACE (2020). Measures for successful outcomes: the Five Capitals approach – a discussion paper. Association for Consultancy and Engineering (ACE). London, UK. Available at: https://www.acenet.co.uk/media/5151/ace-five-capitals-report-2020.pdf

Andreucci, M., Russo, A., & Olszewska-Guizzo, A. (2019). Designing Urban Green Blue Infrastructure for Mental Health and Elderly Wellbeing. Sustainability, 11, 6425. https://doi:10.3390/su11226425

Bagnall, A-M., Freeman, C., Southby, K. & Brymer, E. (2019). Social Return on Investment analysis of the health and wellbeing impacts of Wildlife Trust programmes. Report for The Wildlife Trusts. Leeds Beckett University.

Barton, J., Hine, R. & Pretty, J. (2009). The health benefits of walking in greenspaces of high natural and heritage value. Journal of Integrative Environmental Sciences, 6(4), 261-278, https://doi: 10.1080/19438150903378425

Bell, S., Westley, M., Lovell, R. & Wheeler, B. (2018) Everyday green space and experienced well-being: the significance of wildlife encounters, Landscape Research, 43:1, 8-19, https://doi: 10.1080/01426397.2016.1267721

Berget, B., Ekeberg, Ø. & Braastad, B.O. (2008). Attitudes to animal-assisted therapy with farm animals among health staff and farmers. Journal of Psychiatric and Mental Health Nursing, 15, 576–581.

Calne Town Council et al. (2012). Calne Vision and Scoping Study. https://moderngov.microshadeapplications.co.uk/calnetc/documents/s4720/CalneTownCentreMasterplanVisionandScopingStudy.pdf Accessed 20 September 2019.

Dallat, M., Soerjomataram, I., Hunter, R., Tully, M., Cairns, K. & Kee, F. (2013). Urban greenways have the potential to increase physical activity levels cost-effectively. European Journal of Public Health, 24(2), 190–195.

Davenport, M., Delport, M., Nelson Blignaut, J., Hichert, T. & van der Burgh, G. (2019). Combining theory and wisdom in pragmatic, scenario-based decision support for sustainable development. Journal of Environmental Planning and Management, 62(4), 692-716, https://doi: 10.1080/09640568.2018.1428185

Digital Catapult (n.d.). Growing VR/AR companies in the UK | A business and legal handbook. Report in association with PwC. Funded by Innovate UK. Available at: https://www.pwc.co.uk/intelligent-digital/vr/growing-vr-ar-companies-in-the-uk.pdf

Forum for the Future (2018). The Five Capitals. https://www.forumforthefuture.org/the-five-capitals

Green Halo Partnership (2021). Lepe Country Park case study. Webpage. Available at: https://www.greenhalo.org.uk/case-study/lepe-country-park/

Hooper, T., and Austen, M. (2020). Application of the natural capital approach to Sustainability Appraisal. Final Report. Report prepared as part of the South West Partnership for the Environment and Economic Prosperity (SWEEP) and the Marine Pioneer programme.

Hooper, T., Ashley, M., Mullier, T. and Rees, S. (2020). North Devon Marine Natural Capital Plan. Sustainability Assessment. Report prepared for the North Devon Biosphere Reserve as part of the South West Partnership for the Environment and Economic Prosperity (SWEEP) and the Marine Pioneer programme.

Howarth, M., Griffiths, A., Da Silva, A. & Green, R. (2020). Social prescribing: A 'natural' community-based solution. British Journal of Community Nursing, 25(6), 294-298.

Maack, M. & Davidsdottir, B. (2015). Five capital impact assessment: Appraisal framework based on theory of sustainable well-being. Renewable and Sustainable Energy Reviews, 50, 1338-1351.

Makino, T., Noda, K., Keokhamphui, K., Hamada, H., Oki, K. & Oki, T. (2016). The Effects of Five Forms of Capital on Thought Processes Underlying Water Consumption Behaviour in Suburban Vientiane. Sustainability, 8, 538. https://doi.org/10.3390/su8060538

Maxwell, S. & Lovell, R. (2017). Evidence Statement on the links between natural environments and human health. Report for Defra's Biodiversity and Ecosystems Evidence Programme. Available at: http://randd.defra.gov.uk

Morrison, R. & Hartley, S. (2020). IGNITION Nature-based Solutions Evidence Base. Greater Manchester Combined Authority.

Moseley, D., Connolly, T., Sing, L. & Watts, K. (2018). Developing an indicator for the physical health benefits of recreation in woodlands. Ecosystem Services, 31, Part C, 420-432. https://doi.org/10.1016/j.ecoser.2017.12.008

Nguyen, H.T. (2018). Unpacking local impacts of climate change: learning with a coastal community in Central Vietnam. Natural Hazards, 93, 125–146. https://link.springer.com/article/10.1007/s11069-018-3292-1

Petersen, C. (2020). The South West Coast Path Health and Wellbeing Assessment 2020. Report for the South West Coast Path Association, Plymouth.

Pinto, A. (2017). Spatial Planning for Health: An evidence resource for planning and designing healthier places. Report to Public Health England, London. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/729727/spatial_planning_for_health.pdf

Powys Council (2017). Powys Local Development Plan 2011-2026. Sustainability Appraisal Report. Composite Version Incorporating Matters Arising Changes. September 2017. https://en.powys.gov.uk/article/4906/Sustainability-Appraisal-SA

Rowcroft, P. (2020). Resilience and a capitals approach. Article on AECOM website. Available at: https://aecom.com/without-limits/article/resilience-capitals-approach/

Subramanian, K., Chopra, S., Cakin, E., Liu, J. & Xu, Z. (2021). Advancing neighbourhood sustainability assessment by accounting for sustainable development goals: A case study of Sha Tin neighbourhood in Hong Kong. Sustainable Cities and Society, 66, 102649. https://doi.org/10.1016/j.scs.2020.102649

Tierney, S., Wong, G., Roberts, N., Boylan, A-M. et al. (2020). Supporting social prescribing in primary care by linking people to local assets: a realist review. BMC Medicine, 18: 49.

Weisz, H., Suh, S. & Graedel, T. (2015). Industrial Ecology: The role of manufactured capital in sustainability. Proceedings of the National Academy of Sciences, 112(20), 6260-6264. https://doi.org/10.1073/pnas.1506532112

White, M., Pahl, S., Ashbullby, K., Herbert, S. & Depledge, M. (2013). Feelings of restoration from recent nature visits. Journal of Environmental Psychology, 35, 40-51. https://doi.org/10.1016/j.jenvp.2013.04.002.

White, M., Pahl, S., Ashbullby, K., Herbert, S. & Depledge, M. (2013). Feelings of restoration from recent nature visits. Journal of Environmental Psychology, 35, 40-51. https://doi.org/10.1016/j.jenvp.2013.04.002

White, M. P., Elliott, L. R., Taylor, T., Wheeler, B. W., Spencer, A., Bone, A., Depledge, M. H., & Fleming, L. E. (2016). Recreational physical activity in natural environments and implications for health: A population based cross-sectional study in England. Preventive medicine, 91, 383–388. https://doi.org/10.1016/j.ypmed.2016.08.023.b

Wyles, K., White, M., Hattam, C., Pahl, S., King, H. & Austen, M. (2017). Are Some Natural Environments More Psychologically Beneficial Than Others? The Importance of Type and Quality on Connectedness to Nature and Psychological Restoration. Environment and Behavior, 51(2), 111-143.

Yorkshire Water (2018). A Multi- Capitals Assessment at Little Don: Final Report. Available at: https://www.yorkshirewater.com/media/dgcbfpdl/report.pdf

sweep

Citation: Edwards-Jones, A., Fileman, E., Abrahams, R., & Wheeler, B. (2022). *Building a business case for investment in nature for health - using a Five Capitals Model approach.*
SWEEP Resource for the Investing in Nature for Health project, part of the South West Environment and Economic Prospoerity (SWEEP) programme.

SWEEP is a partnership between the University of Exeter, the University of Plymouth and Plymouth Marine Laboratory.

Funded by NERC, it brings together experts and stakeholders to solve key challenges faced by those working with our natural resources.

UKRI Natural Environment Research Council

sweep
Investing in Nature for Health
RESOURCE

SUPPORTING DOCUMENT

A Five Capitals Model approach –

Building a business case for investment in nature for health

Natural Capital Case Studies

Green space quality enhancements, improving wellbeing

B 16 | Health benefits from coastal wetland ecosystems

Summary: Sutton-Grier & Sandifer (2019) discuss several critical ecosystem services provided by wetlands, including disaster risk reduction, with an emphasis on benefits to human health and well-being. Through a disaster risk reduction lens, the authors show how coastal wetlands can be effective nature-based solutions, minimizing the impacts of disasters by buffering coastal communities from storms and erosion and absorbing flood waters.

Metric: Critical review of ecosystem services

Results: Highlighted are ecosystem services arising from biodiversity in coastal and marine ecosystems such as marshes and seagrass meadows, and include fish nursery habitat, water purification, flood risk reduction, climate modulation, and nutrient cycling. Lesser known cultural ecosystem services from wetlands are also described, namely recreation and leisure, aesthetic, spiritual, cultural heritage and identity, educational, inspirational, sense of place, social, scientific, and existence. There is fragmentary but encouraging evidence to support further development and testing of the links between wetland biodiversity (and specifically wetland microbial biodiversity) and health protective benefits for humans, from infectious and inflammatory-based diseases. In addition, mental and physical health benefits of experiencing healthy wetlands could offset some stress and disease encounters related to disasters. For example, mental and physical stress after a disaster could be alleviated by providing opportunities for at-risk individuals to experience increased exposure to healthy natural and biodiverse environments, including saltmarshes and other wetlands.

Application of findings: Coastal wetlands could be incorporated into strategies for reducing risks posed by disasters and facilitating recovery. Disaster planning authorities could consider the roles that healthy coastal wetlands play in promoting community resilience and human health as part of pre-disaster planning. The roles of wetlands in support of human health and well-being could also be incorporated into coastal resilience and restoration activities undertaken by those military services that frequently interact with these environments. Wetland-based activities could also be developed for referral of individuals and groups from social prescribing services.

B 17 | Impact of type of environment on psychological and physiological responses

Summary: Gidlow et al. (2016) undertook a randomised, cross-over, field-based trial that compared psychological and physiological responses of unstressed individuals to self-paced 30-minute walks in three pleasant but different environments: residential (urban), natural (green), and natural with water (blue). Changes from baseline (T1) to end of 30-min walk (T2), and 30 minutes after leaving environment (T3), were measured in terms of mood, cognitive function, restoration experiences, salivary cortisol, and heart rate variability (HRV).

Metrics: i) Self-reported health using the Short-Form 12 (SF12v2 used to determine Physical and Mental Component Scores), ii) Perceived Stress Scale (PSS), iii) NR-6 Nature-relatedness scale, iv) Total Mood Disturbance (TMD) was assessed, v) Restoration experience was measured through an abbreviated six-item version of the Restoration Outcome Scale, vi) Salivary cortisol was measured as a physiological marker of stress, vii) Ambulatory Heart Rate (HR) and HRV data were collected as an objective measure of exercise intensity, and viii) Rate of Perceived Exertion (RPE) was measured during the walks using the Borg Scale to provide a measure of participant-rated exercise intensity.

Results: Mood and cortisol improved at T2 and T3 in all environments. Green and blue environments were associated with greater restoration experiences, and cognitive function improvements that persisted at T3. Stress reduction (mood and cortisol changes) was observed in all environments suggesting salutogenic effects of walking, but natural environments gave additional cognitive benefits lasting at least 30 min after leaving the environment.

Application of findings: Confirmation of the benefit of such activities in good quality natural environments will be of interest to public health professionals. The additional physical health benefits arising from walking activities in natural green and blue spaces could help justify the continued or increased use of natural resources for such programmes offered by, for example, park authorities.

Manufactured Capital Case Studies

Green space and infrastructure co-developments plus other added benefits for integrating investment in natural and material assets

B 18 | Virtual Reality Technology has potential to improve wellbeing

Summary: White et al (2018) reviewed previous use of virtual reality (VR) nature in health and care settings to consider the potential use of this technology in future. They wanted to assess whether engaging with virtual nature can contribute to enhanced physical and emotional well- being in housebound or mobility-constrained individuals. Examples of application of exposure to VR in nature include provision of distraction from pain; reducing negative emotions, pain, and anxiety in patients during chemotherapy treatments; and reducing heart rates of patients with dementia.

Metric: Critical review of actual and potential applications of VR

Results: VR use can be an alternative to real-world nature in cases when in vivo contact with nature is not possible. A range of possible applications exist for the use of VR technology in psychiatric and medical care, although outcomes need to be measured in a scientifically valid manner. Use by individuals with limited mobility experiencing virtual nature walks or ocean explorations in combination with virtual meetings with friends or family members can improve social capital.

Application of findings: The use of immersive technology has many possible applications in health care; for example, more studies are needed to investigate the effects of exposure to virtual nature for individuals with depression and for cognitive rehabilitation. Commercially, there are numerous tax benefits available to many VR/AR companies who are involved in research, development and intellectual property creation (Digital Catapult, n.d.), hence the potential identified in this paper might be of interest to VR/AR companies in relation to potential markets for content development.

B 19 | Blue health interventions particularly beneficial for mental health

Summary: Britton et al. (2020) aimed to address the gap in understanding the health benefits of blue space within existing interventions. They reviewed studies that have examined the design, structure, benefits and outcomes, if any, of blue care for attaining or restoring psychological and/or physical health and wellbeing.

Metric: Systematic review synthesis

Results: There was some evidence for greater social connectedness during and after interventions, but results were inconsistent and mixed across studies with very few findings for physical health. Overall, positive outcomes were identified for health and wellbeing, especially mental health and psycho- social wellbeing in the short term. Some interpersonal as well as individual effects were evident with a number of studies placing strong emphasis on social connection, sense of belonging, and interaction with others who have shared life experiences, as well as the connective properties of water environments.

Application of findings: The findings suggest how activities in blue space, rather than particular qualities of blue space, might contribute to rehabilitation and health promotion. Groups of people with mental health issues should be targeted more by providers of blue space given the evidence for added benefits from these environments.

B 20 | Potential for self-paying social prescribing services through reduced healthcare costs

Summary: Maughan et al. (2016) assessed the effects of a social prescribing service development on healthcare use and the subsequent economic and environmental costs. The Connect project was operated by Carlisle Eden Mind from October 2011 to March 2014 and involved non-healthcare staff referring patients to local projects, using 'Asset Mapping' to identify available services across third, public and private sectors, self-help, self-management resources, educational, leisure and recreational facilities and fitness-, health- and exercise-related activities. Mean economic impacts were compared between a group of patients with a common mental health condition that spent between 6 and 18 months in the Connect project and a control group with similar conditions but not part of the project. As well as service outcome measures, the financial and environmental impacts were calculated for each outcome using national averages or accepted conversion factors.

Metric: CONNECT social prescribing service outcomes - included the number of GP appointments, prescriptions of psychotropic medications and the number of secondary care referrals (SCR).

Results: No statistically significant differences between the financial and environmental costs of healthcare use between groups. There were larger reductions in healthcare use in the Connect group compared with the control group, although not statistically significant. The Connect project was associated with increased overall financial savings, mainly due to a reduction of SCRs. There were larger reductions in financial cost per patient for SCRs in the Connect group over 18 months (mean diff = £147). There was little difference between groups regarding costs of medication (mean diff = £1) and GP appointments (mean diff = £6) after 18 months. The reductions in financial costs for the Connect group due to reduced healthcare use remained larger than the control group even after service costs were included.

Application of findings: Although this study highlights the difficulty in measuring the financial and environmental impacts of social prescribing services, it nevertheless demonstrates that social prescribing services are potentially able to pay for themselves through reducing future healthcare costs. It will therefore be of interest to funders and managers of social prescribing schemes involving community-based referral mechanisms.

Human Capital Case Studies

Individual physical or mental health gains

B 21 | Positive relationship between nature-dose and mental and social health

Summary: Cox et al. (2017) carried out an urban neighbourhood study in southern England. They used an online survey to collect socio-demographic and lifestyle variables together with health response variables to demonstrate that nearby nature is beneficial to population health.

Metric: The authors used a nature dose-response framework to determine relationships between nature dose type, (frequency and time spent in private green space), intensity (quantity of neighbourhood vegetation cover) of nature exposure and health outcomes (mental, physical and social health, physical behaviour) and nature. They modelled dose-response relationships between dose type and self-reported depression and demonstrated positive relationships between nature dose and mental and social health, increased physical activity and nature orientation.

Results: Health outcomes improved with increasing frequency and duration of exposure to nearby nature. Participants who spent relatively less time out of doors were more likely to have depression and to have worse physical behaviour. The authors found vegetation cover and afternoon bird abundance (but not species richness) were positively associated with lower depression, anxiety, and stress among people that actually encountered these nature metrics.

Application of findings: The authors concluded that if efforts were made to ensure minimal levels of neighbourhood vegetation cover (20%), there is potential for an annual national saving of up to £0.5 - £2.6 billion per year for depression and anxiety alone (based on estimated costs of these disorders to the English economy).

B 22 | Nature-based therapy can assist in treatments of disorders

Summary: Corazon et al 2018 investigated the use of nature based therapy in the form of a forest garden in the treatment of binge eating disorder. Based on acceptance and commitment therapy (ACT) and cognitive behavioural therapy (CBT) this nature-based therapy (NBT) involved guided body and mind awareness exercises in a beautiful park in Denmark. Participants experienced stimuli such as scents and sounds, walking awareness exercises, body scanning and stretching exercises.

Metrics: The study made use of both quantitative and qualitative methods. The authors used Rosenberg's Self-Esteem Scale (RSES) to measure the participants' sense of self-esteem and the Psychological General Well-Being Index (PGWBI) questionnaire, to measure psychological general well-being: this included anxiety, depressed mood, positive well-being, self-control, general mental health, and vitality. Participants also participated in Eating Disorder Examination interviews.

Results: The positive outcomes from the study included decreases in binge eating episodes and increases in general psychological well-being and self-esteem. There were indications that the NBT context made the psychotherapeutic content more accessible to the participants and further helped them transfer the therapeutic gains to daily life after completing treatment.

Application of Findings: The results provide initial support for the feasibility of implementing an ACT-based NBT in the treatment of binge eating disorder.

Financial Capital Case Studies

Investment in nature-based solutions providing economic, health and well-being benefits

B 23 | Economic value of protected areas

Summary: Buckley et al. (2019) evaluated methods to calculate the economic value of protected areas based on the improved mental health of visitors, and compared these to values arising from ecosystem services, biodiversity prospecting, and tourism.

The authors measured Quality of Life for visitors at the trailheads of two Australian subtropical national parks, using a Personal Wellbeing Index (PWI). Visitor PWI was compared against national statistics to estimate per capita differentials (ΔPWI). Published estimates of $/QALY were used to convert ΔPWI to $/visitor. The total annual value of visits for Australia was obtained by multiplying this rate by protected area visitation rates. An online survey sample was used to collect data on protected-area and non-park green-space use over a 12 month period (QOL, measured as PWI; and socioeconomic, demographic, and physical health parameters).

Metrics: Personal Wellbeing Index (PWI), QALYs.

Results: The pilot studies, for visitors on-site, found ΔPWI= 2.4–3.4%. Using ΔPWI= 2.5%, a $/QALY value of US $200,000, and an Australian adult population of 20M, the annual health services value of Australia's national parks is ~US$100 billion, approx. 7.5% of Australia's GDP, 1.6X the entire annual turnover of Australia's tourism industry. Scaling up, a conservative global estimate using QALYs is US$6 trillion p.a, representing approx. 4% of global ecosystem services value.

Application of findings: Health service values will be of interest to policymakers and health service providers; methods will be of interest to site managers, researchers and evaluators at local and national scales. (Note the large variation used within studies, even in these case study examples, of the economic value per QALY).

B 24 | Green infrastructure investment is cost-effective while improving quality of life

Summary: Thompson et al. (2019) evaluated whether the implementation of a programme designed to improve the quality of, and access to, local woodlands in deprived communities in Scotland, UK, was associated with lower perceived stress or other health-related outcomes. They assessed a physical intervention and combined social and physical intervention as part of the Forestry Commission Scotland's Woods In and Around Towns (WIAT) programme. Physical intervention included new or resurfaced and drained footpaths, signage, and entrance features undertaken over a period of eight months. Social interventions consisted of a programme of community-level activities and events, e.g., guided walks, 'family fun' days, 'scavenger hunts', and woodland based classes for schoolchildren. Repeated, cross-sectional surveys of intervention and control communities were undertaken in three waves, across three sites. A cost-consequences analysis (CCA) was used to present the total cost of the interventions in relation to the primary and secondary outcomes of the interventions. An exploratory cost-utility analysis (CUA) was also conducted from the EQ-5D responses for the WIAT interventions over the timescale of the study.

Name of measures: Perceived Stress Scale (PSS), quality of life EQ-5D, physical activity measured using the International Physical Activity Questionnaire, connectedness with nature measured using the Inclusion of Nature in Self Scale, Social cohesion measured based on three items from the English Citizenship Survey, QALYs.

Results: The average cost per person for the physical intervention was £7.68, (95% CI £7.67–£7.69) and £11.80, (95% CI £11.79–£11.82) for both physical and social interventions. The CUA compared the incremental expected cost of the physical intervention and both the physical and social interventions per individual in the eligible population with estimated QALYs gained from the intervention, based on the adjusted difference of the health-related quality of life (HRQoL) utilities of the EQ-5D.

The CUA suggested that for the physical intervention the cost per QALY was £935, (95% CI £399) while for the combined physical and social interventions the cost per QALY was £662, (95% CI £206). Assuming a societal willingness to pay of at least £10,000 per QALY, the interventions would only have to generate lifetime QALYs of 0.0012 on average for the interventions to be cost-effective.

Application of findings: These findings will be of interest to those required to undertake assessments of natural environment interventions. The inform government policymakers, landowners, stewardship communities, practitioners and NGOs engaged in supporting community health and wellbeing.

Exploring the literature – Five Capitals Themes and Objectives

'These tables and descriptions of the five capitals highlight further examples of themes that relate to each capital, as well as the kind of business objectives these could inform. These examples are drawn from academic literature[1] that highlight cases where the Five Capitals Model has been applied within real environmental contexts.

We hope these will help you identify themes relevant to your own work, generate new ideas, and support your understanding of how particular themes, issues, programmes, activities and even structures within your organisation align with the five capitals and might best be positioned within the model.

Manufactured Capital

Most interactions between natural and human capital are not direct, but are facilitated by manufactured capital in the form of industrial production facilities, communication devices, and built infrastructure. This capital comprises, for example, buildings, transport systems, energy, water, waste infrastructure and all durable production and consumer goods, including machinery and information technology. There is a need to consider the trade-off between manufactured capital providing essential goods, services, and shelter for human well-being, and its potential to impact negatively on natural capital. Solutions will need to find a balance between the natural and manufactured capital.

There is less detail on this capital within environmental and sustainability literature, but some examples include:

Examples of **themes** that relate to manufactured capital
The availability and suitability of renewable energy infrastructure, public transport and flood protection infrastructure
Physical resources, such as transport infrastructure (i.e. roads, bridges, tunnels), transport vessels, flood dykes, farms, domestic water supply systems
Equipment – in a local planning context, for example, might include tools and machinery that contribute to the provision of services, rather than being part of the output itself
Technological solutions i.e. communication mechanisms
Local neighbourhood indicators of various SDGs include: Road density as a proxy indicator for air quality among buildings in a neighbourhood
Energy consumption rates of households and buildings as an indicator of clean energy
Proximity of communities to solid waste recycling points as an indicator for responsible consumption and production

Examples of **objectives** that relate to manufactured capital
• Provide suitable housing that meets the needs of the population and maximise affordable housing
• Improve energy efficiency and use of sustainable construction materials
• Make public transport, walking and cycling easier and more attractive
• Make public transport, walking and cycling easier and more attractive

[1] Sources include ACE (2020); Hooper et al. (2020); Hooper & Austen (2020); Nguyen (2018); Maack & Davidsdottir (2015); Makino et al. (2016); Subramanian et al. (2021), and Weisz et al. (2015).

Natural Capital

Human health can be directly or indirectly affected by a wide range of ecosystem services. For example, the crop pollination and food production, the availability of fresh water and clean air, and carbon sequestration for climate regulation. Key themes identified in the literature that relate to natural capital include: biodiversity; air quality; land quality; water quality; climate change, sustainability; and protected area management.

Examples within environmental and sustainability literature include:

Examples of **themes** that relate to natural capital
The ability of the environment to sequester carbon and to protect infrastructure from flooding and erosion
Ecosystem services and benefits i.e. water quality, maintenance of populations and habitats, erosion control, flood protection, climate regulation
Habitats as assets within an ecosystem
Asset registers i.e. for marine environments - geology, rock, sediment, saltmarsh, mussel beds, commercial finfish and crustaceans, wetland birds, marine mammals
Natural resources, such as groundwater, gardens, land for crops, plant types, shellfish species, forests, solar energy, soil fertility etc
Green area density as indicators of potential habitat for life, and effect on microclimate

Examples of **objectives** that relate to natural capital
• Protection and enhancement of biodiversity and important wildlife habitats
• Protection and enhancement of the countryside, natural landscape and townscape
• Maintenance and enhancement of heritage assets and their settings
• Maintenance and enhancement of air quality
• Protection of high-grade soils
• Reduced disturbance to water birds, sea birds and marine mammals
• Designated bathing waters reach guideline standards
• Estuarine and coastal water bodies reach appropriate standards under the Water Framework Directive
• Reduced disturbance of intertidal mudflats in estuaries from recreational bait collection
• Reduced quantity of plastic waste and litter on beaches
• Connections to a water supply

Human Capital

Human capital can be evidenced through the wellbeing, skills and education benefits that individuals gain, both from helping to set up, and participate in, programmes, projects and activities that deliver positive health and wellbeing outcomes.

Examples from literature include:

Examples of **themes** that relate to human capital
The required skills, employment opportunities and need to encourage behaviour change around, for example, transport use
Health, wellbeing and happiness
Leisure
Mobility
Knowledge, from education and training
Identity
Self-respect

Examples of **objectives** that relate to human capital
• Provide access to learning, training, skills and knowledge for everyone
• Diversify the range of local employment opportunities
• Improve health of population and reduce health inequalities
• Strengthen research, technology and innovation
• Improve access to health services

Social Capital

This is a set of shared values and structures that allows individuals to work together in a group to effectively achieve a common purpose. Key themes within this capital include community engagement, public services (for example, community-based social prescription programmes) and equality.

Examples from literature include:

Examples of **themes** that relate to social capital
The opportunity for community-led energy projects
Social cohesion
Community networks with shared norms, values and understanding
Degree of neighbourliness and kinship arising from particular actions or decisions
Knowledge, skills and capabilities
Connections between people, and between people and systems
Extent and type of civil engagement in voluntary actions
Extent of political participation

Examples of **objectives** that relate to social capital
• Reduce crime and the fear of crime
• Promote development which supports community wellbeing and cohesion, especially in those areas facing multiple deprivations
• Use information technology to promote and facilitate opportunities within the community planning process including buildings and services which can be utilised by the community, using business networks to provide opportunities for new enterprise
• Contribute to a diverse and growing population with a balanced demographic structure
• Fully engage with and positively involve the local community and other interested parties at all stages of the planning process
• Effective transmission of information about public services

Financial Capital

Themes within this capital include returns on investment, cost-benefit analyses, project financing mechanisms and economic measures of health and wellbeing.

Examples from literature include:

Examples of **themes** that relate to financial capital
Mechanisms to encourage related inward investment (climate change)
Cash, loans, bank savings, credits and insurance
Social return on investment
Conversion of health and wellbeing metrics to economic values
Household income

Examples of **objectives** that relate to financial capital
• Foster sustainable economic growth
• Contribute to a private sector that is a high-level economic contributor
• Provide export opportunities
• Become a location of choice for start-up businesses
• Ability to invest in better water quality

References

Britton, E., Kindermann, G., Domegan, C. & Carlin, C. (2020). Blue care: a systematic review of blue space interventions for health and wellbeing. Health Promotion International, 35, 50–69. https://doi: 10.1093/heapro/day103

Buckley, R., Brough, P., Hague, L. et al. (2019). Economic value of protected areas via visitor mental health. Nature Communications, 10, 5005. https://doi.org/10.1038/s41467-019-12631-6

Corazon, S., Sidenius, U., Vammen, K., Klinker, S., Stigsdotter, U., & Poulsen, D. (2018). The Tree Is My Anchor: A Pilot Study on the Treatment of BED through Nature-Based Therapy. *International Journal of Environmental Research and Public Health*, 15(11), 2486. MDPI AG. Retrieved from http://dx.doi.org/10.3390/ijerph15112486

Cox, D. T., Shanahan, D. F., Hudson, H. L., Fuller, R. A., Anderson, K., Hancock, S., & Gaston, K. J. (2017). Doses of Nearby Nature Simultaneously Associated with Multiple Health Benefits. *International journal of environmental research and public health*, 14(2). https://pubmed.ncbi.nlm.nih.gov/28208789/

Gidlow, C., Jones, M., Hurst, G., Masterson, D., Clark-Carter, D., Tarvainen, M., Smith, G. & Nieuwenhuijsen, M. (2016). Where to put your best foot forward: Psycho-physiological responses to walking in natural and urban environments. *Journal of Environmental Psychology*, 45, 22-29, https://doi.org/10.1016/j.jenvp.2015.11.003

Maughan, D., Patel, A., Parveen, T., Braithwaite, I., Cook, J., Lillywhite, R. & Cooke, M. (2016). Primary-care-based social prescribing for mental health: an analysis of financial and environmental sustainability. Primary Health Care Research & Development, 17, 114–121. https://doi:10.1017/S1463423615000328

Sutton-Grier, A.E. & Sandifer, P.A. (2019). Conservation of Wetlands and Other Coastal Ecosystems: a Commentary on their Value to Protect Biodiversity, Reduce Disaster Impacts, and Promote Human Health and Well-Being. Wetlands, 39, 1295–1302. https://link.springer.com/article/10.1007/s13157-018-1039-0

Thompson, C. W., Elizalde, A., Cummins, S., Leyland, A. H., Botha, W., Briggs, A., Tilley, S., de Oliveira, E. S., Roe, J., Aspinall, P., & Mitchell, R. (2019). Enhancing Health Through Access to Nature: How Effective are Interventions in Woodlands in Deprived Urban Communities? A Quasi-experimental Study in Scotland, UK. Sustainability, 11(12), 3317. https://doi.org/10.3390/su11123317

White, M., Yeo, N., Vassiljev, P., Lundstedt, R., Wallergård, M., Albin, M. & Lõhmus, M. (2018). A prescription for "nature" – the potential of using virtual nature in therapeutics. Neuropsychiatric Disease and Treatment, 14, 3001–3013. https://psycnet.apa.org/doi/10.2147/NDT.S179038

Citation: Edwards-Jones, A., Fileman, E., Abrahams, R., & Wheeler, B. (2022) *Building a business case for investment in nature for health - using a Five Capitals Model approach: Further Case studies.* Supplementary material to SWEEP resource produced as part of the Investing in Nature for Health project.

SWEEP is a partnership between the University of Exeter, the University of Plymouth and Plymouth Marine Laboratory.

Funded by NERC, it brings together experts and stakeholders to solve key challenges faced by those working with our natural resources.

Investing in Nature for Health
REVIEW

More than just a skate park?

A review and practical guide on how to make urban green space more accessible to adolescents to support health and wellbeing

Why does this report matter?

- **1 in 6 young people globally, aged between 16-24, have symptoms of a common mental health disorder such as depression or anxiety.[1]**
- **Half of all mental health problems manifest by the age of 14, with 75% by age 24.[2]**
- **Children from low-income families are four times more likely to experience mental health disorders than children from wealthy families.[3]**
- **Children are spending more free time engaged in indoor sedentary activities than in active outdoor play in the UK, with 21 minutes less per day spent in outdoor play in 2015 compared to 1975.[4]**
- **Since 2010, austerity policies in the UK have contributed to the challenging questions of how we equitably invest in green space.[5]**
- **The Covid-19 pandemic has emphasised the value of accessible, healthy green spaces for all.[6]**

What is this report about?

This report is a summary of recent research and related literature on urban green space and how to improve access for adolescents. Green spaces provide an opportunity to support and improve mental and physical health across all ages, including adolescents. Highlighting case studies from across the world, this report highlights new insights and provides practical advice on how to improve urban green space for adolescents, challenging the widely held view that all young people want are built resources such as skate parks.[7]

The report looks at both planning and design (the development of new elements and structures) and management (the maintenance and development of existing structures and spaces), as well as how best to engage adolescents in these processes to ensure their use and benefit from green spaces.

Who should read this?

Individuals and organisations involved in the planning, design, and management of green space as well as those who work with adolescents. These might include:

- Local Authorities
- park/green space managers
- urban planners
- conservation charities
- youth charities, and
- education institutes (schools, colleges, and universities).

Is a half-pipe the answer?

Green space is a vital resource for people of all ages.[8] It is a place to socialise, exercise and contributes to wellbeing. Recent reviews have found that provision of, and good access to, quality green space can generate positive impacts on adolescents' mental health and well-being.[9,10] Exposure to nature is associated with higher self-esteem and quality of life, and reduced symptoms of depression and attention deficit disorder.

This report considers 'green space' to be any area of urban or rural vegetated land, including waterside areas.

This includes both public and private spaces such as parks, gardens, playing fields, children's play areas, woods and other natural areas, grassed areas, cemeteries and allotments, green corridors, disused railway lines, rivers and canals, coastlines, derelict, vacant and contaminated land which has the potential to be transformed.[12]

This report refers to adolescents as individuals aged between 10 and 19, as defined by the World Health Organisation.[1]

The US Department of Health & Human Services describes this time as "A period of great potential as young people engage more deeply with the world around them. Adolescents typically grow physically, try new activities, begin to think more critically, and develop more varied and complex relationships".[11]

Adolescents are at a stage in life where they are beginning to develop independence, yet most are unable to purchase their own living space or travel far from home.[13] Green space offers an important opportunity to fulfil this need. It is a resource that is usually free to use, without time limits, and distributed widely (although it is acknowledged that there are multiple individual, social and cultural barriers to access). Yet, whilst adolescents are a significant user group of urban green space, these parks and public areas are more often designed with young children and adults in mind. When adolescents are considered, it is often with the misplaced view that all they want are skate parks.

"Parks are quite good because the thing with parks and stuff they can't really kick you out. So you can stay as long as we are not affecting people". **Girl, 14 years old.**[13]

"There is nothing to do for young people of my age, it's all for children, the swings and slides. They should put things for us, as well." **Girl, 14 years old.** [13]

These remarks are taken from a 2005-07, 18-month study in Glasgow, looking at how 56 teenage participants use parks and green space. The study found parks are very important in the narrative of the participant's daily lives but that they felt out of place in these spaces due to the lack of facilities provided for them.[13]

Whilst adolescents recognise green space as a potential place for socialising and recreation, they feel these spaces need to be designed with a greater awareness of adolescents' needs in mind.[13] Not only will this help indicate to other users that adolescents are welcome, allowing them to feel more comfortable, it will increase the likelihood of their use of the green spaces and deriving a health and wellbeing benefit from them.

A diversity of environments, facilities and programming is likely to enhance the inclusivity of public green space. Recent campaigns have started to push for more to be done on the inclusivity of public spaces, especially parks, for example 'Make Space for Girls', which works specifically to encourage and provide solutions to make these spaces more accessible and appealing to girls and young women.[14]

Creating adolescent-friendly green spaces

Drawing on case studies, this section explores existing and innovative approaches to creating green spaces that offer a more attractive, safe, and healthy place for adolescents. Due to the limited UK evidence available, global examples have been selected, although focused on countries with similar contexts to the UK.

We acknowledge that there are other issues and dimensions not explored in this brief summary, but the bibliography provides links to some valuable resources and more detailed discussion.

The following key approaches and design features are considered.

- **Co-designed approach**
- **Social space**
- **Nature**
- **Safety**
- **Wi-fi**
- **Art**
- **Events**
- **Youth council**

Co-designed approach

When planning or changing a public space, public support is essential. Co-designing the space with key members of the local community will ensure important local features and sensitivities are considered before the design phase, and increase the likelihood of its use.

Co-designing the space with key members of the local community will ensure important local features and sensitivities are considered during the design phase, and can increase the likelihood of its use. Drawing on research on co-production, there are five key elements for success.[15]

- Park managers and users of parks are active agents in the process.
- Relationships are equal and all contributions valued.
- The partnership is reciprocal and has mutual benefits.
- Participation informs design and delivery of services.
- The participation of users is encouraged and supported by local organisations (such as the local schools/colleges, community youth groups, community adult groups etc.).

Traditional forms of engagement such as stakeholder meetings held in council buildings are unlikely to attract high adolescent turnout, so communication styles should be adapted. Methods such as online surveys via social media, and interesting competitions or incentives, have proved successful in increasing teenage participation.[16] Working with youth services, schools and voluntary sector groups offering services for adolescents can help design appropriate forms of engagement.

Working with the whole community, not just adolescents, will foster a healthy understanding of the motivations behind each green space user group, and will help other users understand why, and how, adolescents want to use green space.

Case study: Growing up Boulder

Growing up Boulder (GUB) is a teenager friendly initiative in the city of Boulder, Colorado, that started in 2009. Their work aims to ensure teenagers help to inform projects such as the design of public spaces, transit systems, housing, and resilience planning. The GUB co-ordinator reported that "research shows incorporating the views of adolescents in the design of parks and public spaces leads to increased satisfaction by youth, and feelings of increased interconnectedness with the community".[17] In 2016, the City of Boulder Parks and Recreation department began planning the upgrade of four urban parks, and collaborated with GUB to ensure adolescents were engaged in discussions about how to create more opportunities for them in the city parks. In total, a group of adolescents, undergraduates, community leaders, and partners spent 15 hours consulting together.

"I liked how they actually asked the kids and not just assumed [what we wanted]."

"I think kids would go to more places because we designed it."
[Statements from adolescents who participated in the consultation] [18]

GUB has been running for 11 years and has influenced over 100 city and community projects by contributing a 'youth voice' to their design and development.[19] The initiative engages children of all backgrounds to ensure their input is included in local government decisions around the design of public spaces. Growing up Boulder is one of a few studies that monitors the effects and impact of co-production with adolescents, demonstrating its value.

Social space

Adolescents want outdoor spaces where they can socialise, be in nature, and feel safe.[20]

"I don't use skate parks because I don't have a skateboard and do not like skate boarding, also I'm a girl and there's not a lot of things/activities for us. Very unfair and that is why girls don't get outside as much." **Teenage girl responding to a survey about parks in her area.[21]**

It is clear from perception surveys and reports that adolescents want outdoor spaces where they can socialise. The stereotype for socialisation provision is an old shelter, with graffiti and broken glass, that can easily become a location for anti-social behaviour.[22] However, there are good examples of social spaces in parks created with adolescents in mind, where adolescents have their own space, whilst still being connected to other areas and park users.[21] Traditional options such as benches can be welcome, but other, more creative, designs should also be considered.
An Australian survey in 2016 asked 336 adolescents (48% female and 52% male) what they would most like to see in green spaces.[21]

The top 5 suggestions were:

- a place to hang out
- playful elements
- ball courts
- social seating, and
- fitness and climbing.

In a similar study in Sweden in 2016, adolescents discussed how areas providing swings and age-appropriate playground equipment e.g. flying foxes, structures for climbing, should also offer spaces for seating and socialising.[23] A recent review found that, as with other age groups, amenities such as drinking fountains, toilets and paths were also mentioned as important factors for encouraging socialising in green space.[24] The review suggested that providing a range of seating options and facilities creates opportunities for social meetings and enables green space to become multifunctional places.

There is clearly a challenge to creating integrated, inclusive, welcoming spaces, whilst also providing facilities suitable for the needs and wants of specific groups, such as adolescents. Whilst there are no simple solutions, this emphasises the need for a careful, co-designed approach to designing social spaces that feel safe and welcoming for all. Groups of adolescents can sometimes be perceived as problematic and may feel excluded from public facilities by other users who feel a greater entitlement to be there.

In Greater Shepparton, Australia, a report on creating space for teenagers discusses a way to combat perceived, or actual, conflict by ensuring the whole community is involved in designing communal spaces.[21] Co-design with the community is a strong theme across the literature as a way of addressing the tensions around public space and mitigating potential issues. This emphasises that design with, and for, adolescents should also consider the whole community, and other dimensions of access and inclusivity.[12, 25]

Case studies

Image: publicworkshop.us

Public Workshop works with adolescents and their communities to build interesting park and street 'furniture'.[26] In 2016, 200 students created designs for seating that was to sit between an elementary school (5 to 10 years old) and middle-high school (11 to 18 years old) in Phoenix. The winning design mimicked a beehive structure.

Image: Youth Space, Queen Elizabeth Olympic Park

Islington Spafields Park Gimme Shelter project (2003). The design of the regeneration site was created through a particpatory process with local young adults (incuding nine schools in the area) with particular focus on groups that are less likely to be involved. The regeneration significantly reduced vandalism and anti-social behaviour in the preceeding years.[27]

Nature

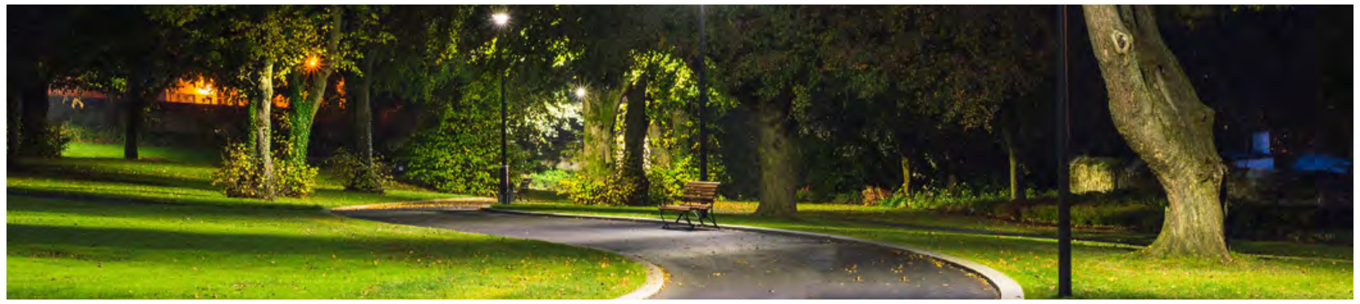
Studies show that one reason adolescents visit parks and green spaces is to be closer to nature.[28] They express preferences for aesthetically pleasing spaces, with diverse natural features including water, trees and flowers, as well as appreciating sensory experiences such as bird song. Nature also provides a backdrop to their activities: natural planting arrangements can be used to create multifunctional green space, providing less visible or private areas where adolescents can find space away from other people.[22, 24]

Traditional planting schemes do not necessarily meet these needs, and there has been a move towards more biodiverse landscaping in recent years, such as the creation of urban meadows.

Safety

In 2016, the Heritage Lottery funded State of the UK Public Parks report found that only 53% of park managers reported their parks were in a good state (down 7% from 2014). 55% of managers expected their revenue to be cut by 10-20% over the next three years, with 38.6% expecting to see the condition of their parks to decline due to less maintenance work. They expected this to have an impact on various issues such as the aesthetics, facilities and safety of the parks.[31]

> "Over time, we expect serious maintenance issues to become apparent in parks, such as keeping tarmac paths in good condition, replacing play equipment, and tree maintenance. Gradually, the decline in the condition of parks will make parks more difficult, less pleasant and less safe to use, impacting on the health and wellbeing of communities that rely on them. This decline will be very challenging and expensive to reverse."
> **Written evidence submitted to the House of commons Public Park report from the Ramblers [PSK151]**[32]



In a 2010 study of parks in Scotland young adults cited safety and cleanliness as an important factor for using the park. Broken glass, needles, dog fouling and vandalised equipment are all, perhaps unsurprisingly, deterrents to using a park.[33] Young adolescents interviewed in the study cited overgrown dark places and lack of functioning lighting as safety concerns.

In regard to lighting in particular, best practice can be drawn from outdoor skate parks.[34]

- Lighting on a timer (agreed with residents) to switch off at a given time at night.
- Lighting used to communicate when the park is about to close (dimming or flashing lights).
- Adequate lighting on paths leading from the park back to residential areas to boost security. Eradicate dark spots on routes back to people's residence and/or create 'safe routes' or zones that are covered by CCTV and lighting.

Outdoor WiFi

For many young people being connected online is a huge priority. However, access to the internet at home can be varied and limited, and there is a digital divide between those that can and cannot afford mobile internet service.

Free WiFi in parks can create a safe space to go where adolescents can do their homework and socialise whilst, crucially being outside and benefitting from green space. Many examples of organisations working within parks, state free WiFi as a priority cited by adolescents.[18, 21]

Art

Art works can enhance the general experience, interest, and appeal of public green spaces. While art is not specific to adolescents, certain types of art or augmentation may present opportunities to make spaces feel particularly welcoming to this age group and provide additional activities to those more typically on offer. For example, public art can include QR codes that link to online resources, or a bespoke hashtag and selfie spot set up to facilitate social media posts. Sculptures can be loaned from local artists, or can be created with local schools and colleges - sometimes, more temporary installations can be an advantage, as this keeps it interesting.[35] Teenagers want interactive spaces with art they can touch and feel, not that is cordoned off.[36]

Public art experiences for adolescents could incorporate the following elements:

- interactive art that changes regularly and can be touched
- art that links to social media
- art that can be borrowed temporarily, or ephemeral art
- art that is created by local groups/schools/students, or
- engaging activities such as a 'geocaching' type art trails using QR codes and social media.

Events

Hosting events in a park makes them feel like a destination to go to. Whilst events do not need to be specifically adolescent-focused, event planning should ensure they are inclusive to all. Events can be expensive to organise and run, but appropriate spaces within a park can be hired out, and events for adolescents encouraged. Parks in some places run their own youth programmes, including exercise classes, cooking classes, drop-in art sessions etc.

Key elements to consider when planning park events for adolescents are:[37]

- movie nights, food vendors and live music are among the most popular events
- events should capitalise on the unique assets the park has to offer (for example poetry or music in a covered band stand, mindfulness sessions in a wildflower area, sports/games if there is a large enough open area), and
- events cannot be all things to all young people and should not be expected to appeal to every teenager.

Youth Council

Around the world, and in many UK local authority areas, youth councils have been created. Participants contribute to local issues and there are opportunities to be involved in the UK youth parliament.[38] However, parks can also have their own youth councils. Although this is a resource intensive option, it could be hosted by local schools or youth organisations, or be associated with existing park community groups. Participants sign up to serve for a period of time (generally a year) and are responsible for:

- developing the vision for the park;
- suggesting and organising events (such as movie nights/park cleans/park festivals); and
- reviewing changes to the park.

Those on the youth council also gain valuable experience that can help them in the future, including:

- planning skills (in relation to events)
- balancing the needs of young people with those of other park users
- communicating ideas effectively with peers and organisers/councils etc.
- prioritising resources
- decision making skills
- working as a team towards a common goal, and
- communicating in a professional manner.

A recent project 'Kick The Dust: Future Proof Parks' has aimed to support and encourage young people to join their local 'friends of' park groups, another key mechanism by which young people can have a voice if supported to do so.[39]

Case study

The Legacy Youth Voice, Queen Elizabeth Olympic Park, London, was formed in 2008 (four years before the 2012 Olympics) and currently has 200 youth members.
The aim of the Legacy Youth Voice is to:

- influence and shape the Park;
- review and input into design plans and strategy documents;
- be the voice out to young people about what is happening in the Park;
- help to develop opportunities for young people to get involved in the Park; and
- provide development and personal growth opportunities for young people involved in the group.[40]

The Legacy Youth Voice has been successful, recruiting new members every year. It is still running and involved in influencing decisions about the park.

Looking to the future

Mental health problems are increasing in children and young people in the UK

The statistics around adolescent mental health are worrying. Poor mental health affects low-income families disproportionately, and mental health problems in adolescence have the potential to persist through adult life, leading to long-term impacts on workplace productivity and sickness. These impacts have been exacerbated and intensified through the Covid-19 pandemic.[41] Access to green space is by no means a full solution to these challenges, but may be a useful part of how we approach them in the coming years.

Adolescents are a particularly vulnerable, yet underserved group

Adolescence is a time of change and experimentation. Young people typically like to try new things, develop their identity and may move between social groups as they explore their own interests and motivations. This time of transition and uncertainty, can make them vulnerable to exploitation and engaging with risky behaviours such as unprotected sex and experimentation with illegal substances. As a result, this 'adolescent' stage of life can often lead to increased incidence of physical, and mental health and wellbeing difficulties, that if left unchecked, can develop into life long issues. Spending time in quality green spaces can be part of the solution. It is important we look beyond the stereotypical perception that adolescents are only interested in parks to engage in antisocial behaviors such as drawing graffiti, smoking and drinking alcohol. We know that many adolescents value and benefit from the health and wellbeing opportunities offered by green spaces, and their facilities, and this needs to be encouraged and rolled-out more widely to this age group.

Working in collaboration with adolescents, to understand why and how they want to use their local green spaces, will help authorities and managers provide healthier, more inclusive public places.

How can we make the most of green space for adolescents' health and wellbeing?

A multi-faceted approach is required for supporting and delivering improvements in adolescents' health and wellbeing and, in light of the growing evidence, access to suitably designed and managed green space may be an important part of the solution.

Despite a relative lack of specific research around adolescent health, there is substantial and growing body of evidence that shows human mental health and wellbeing can be improved by spending time outside in green space. Physical activity in green space has been estimated to have a health value of £2.2 billion per year for those aged 16+ in England.[42] In London, green space is estimated to save £370 million per year by contributing to improved mental health.[43]

There is a clear incentive, therefore, to invest not just in creating new, accessible and well co-designed green space, but in managing the green space we already have, and preventing its further degradation.[31] Health and wellbeing benefits for young people at population scale could be realised through engaging adolescents in using these spaces, and facilitating greater, inclusive access to green space. These issues should also be considered in the wider context of making the most of green space for people's health and wellbeing more generally.[44]

Inclusivity, diversity and discrimination in our natural environments are recognised as vital issues governmental and non-governmental agencies must tackle, engaging society at large.[12, 45]

The challenges of engaging adolescents in the use of green space

The research and case studies summarised here make clear that many adolescents want to spend time in green space and take advantage of the many health benefits from doing so. There are various challenges, however, to engaging adolescents in the use and benefit from green spaces. It is important to consider these before undertaking a green space enhancement project.

- Green space is typically designed with young children, families, and adults, in mind, rather than adolescents (although there are a growing number of innovative examples from across the world). Adolescents want to feel included in the design of these spaces and made to feel welcome by other users.
- Adolescents can feel uncomfortable or unsafe in green spaces, due to factors such as poor lighting, poorly maintained grass and planting areas, run down facilities, and litter problems.
- As with other groups in society, adolescents relish the diversity of opportunities afforded by green spaces. Typical adolescent facilities such as skate parks and socialising areas are important, but so are lush green spaces, with trees, flowers and running water, social seating, attractions such as art displays and events, and spaces designed especially for adolescent use, yet remain an integral, and connected part of the overall green space.
- Engaging adolescents in planning, creating and maintaining green spaces for them is key.
- Adolescents are often an underserved and under-heard audience. They exhibit just as much diversity in needs and wants for green spaces as other age groups. In many places there is already an established infrastructure of organisations working and engaging with adolescents, including schools, youth groups, sport societies and charities, and youth workers who are established in the community. Working with these established organisations and relationships to engage adolescents in green spaces can help reduce barriers and challenges for all.

What next?

This resource offers insights into how green space might be better managed and used to deliver health and wellbeing benefits to adolescents, however, there is clearly a need to know more. Further collaborative research is needed to understand how best to improve and manage our green spaces to benefit adolescents' mental and physical health and wellbeing, developing evidence that can prompt further debate, secure further funding and deliver action.

This work raises many important questions for those working in this field. We leave you with a few of these and invite you to share your experiences via the Investing in Nature for Health webpages.

- How can funding and development in this area address these issues?
- Are there alternative sources of funding for activities focussed on adolescents – beyond those we've currently highlighted in our alternative funding mechanism resource?
- How can the inequalities of access to green space for adolescences be addressed?
- What are the key barriers to engagement, and are there examples of inspiring practice that successfully tackle these?
- How can green spaces be managed for both adolescent health and wellbeing benefit and environmental gains (such as increased biodiversity)?
- What characteristics of green spaces make them amenable to the diverse preferences and needs of adolescents without excluding others?
- Do you have successful examples of engaging and sustaining adolescents' involvement in green space activities?

References

1. WHO.int. 2021. Adolescent health. [online] [Accessed 2 July 2021].
2. Kessler, R., Berglund, P., Demler, O., Jin, R., Merikangas, K. and Walters, E., 2005. Lifetime Prevalence and Age-of-Onset Distributions of DSM-IV Disorders in the National Comorbidity Survey Replication. Archives of General Psychiatry, 62(6), p.593.
3. Morrison Gutman, L., Joshi, H., Parsonage, M. & Schoon, I. 2015 Children of the new century: mental health findings from the Millenium Cohort Study. London: Centre for Mental Health
4. Mullan, K., 2018. A child's day: trends in time use in the UK from 1975 to 2015. The British Journal of Sociology, 70(3), pp.997-1024.
5. Mell, I., 2020. The impact of austerity on funding green infrastructure: A DPSIR evaluation of the Liverpool Green & Open Space Review (LG&OSR), UK. Land Use Policy 91, 104284.
6. Day, B., 2020. The Value of Greenspace Under Pandemic Lockdown. Environmental and Resource Economics, 76(4), pp.1161-1185.
7. Bishop, K. and Corkery, L., 2017. Designing cities with children and young people. New York: Routledge Taylor & Francis Group.
8. Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A., de Vries, S., Triguero-Mas, M., Brauer, M., Nieuwenhuijsen, M., Lupp, G., Richardson, E., Astell-Burt, T., Dimitrova, D., Feng, X., Sadeh, M., Standl, M., Heinrich, J. and Fuertes, E., 2017. Exploring pathways linking greenspace to health: Theoretical and methodological guidance. Environmental Research, 158, pp.301-317.
9. Bray, I., Sinnett, D., Reece, R., Hayward, R. & Martin, F. 2020 New review finds that better access to green spaces has a beneficial impact on anxiety and depression in young people, aged 14 to 24 years. UWE Bristol Centre for Sustainable Planning and Environments blog. [Accessed 2 July 2021]
10. Zhang, Y., Mavoa, S., Zhao, J., Raphael, D. and Smith, M., 2020. The Association between Green Space and Adolescents' Mental Well-Being: A Systematic Review. International Journal of Environmental Research and Public Health, 17(18), p.6640.
11. USDHHS. Adolescent Development Explained. [Accessed 2 July 2021].
12. PHE, 2020. Improving access to greenspace. A new review for 2020. London: Public Health England. [Accessed 2 July 2021]
13. Day, R. and Wager, F., 2010. Parks, streets and "just empty space": the local environmental experiences of children and young people in a Scottish study. Local Environment, 15(6), pp.509-523.
14. Make Space for Girls. [Accessed 2 July 2021]
15. Heaton, J., Day, J. and Britten, N., 2015. Collaborative research and the co-production of knowledge for practice: an illustrative case study. Implementation Science, 11(1).
16. unicef, 2018. Shaping urbanization for children A handbook on child-responsive urban planning. [Accessed 2 July 2021].
17. Derr, V. and Kovács, I., 2015. How participatory processes impact children and contribute to planning: a case study of neighborhood design from Boulder, Colorado, USA. Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 10(1), pp.29-48.
18. Mintzer, M., 2017. Growing Up Boulder's Teen-Friendly Parks Report.[Accessed 2 July 2021].
19. Growing Up Boulder, 2021. [Accessed 2 July 2021].
20. Loukaitou-Sideris, A. and Sideris, A., 2009. What Brings Children to the Park? Analysis and Measurement of the Variables Affecting Children's Use of Parks. Journal of the American Planning Association, 76(1), pp.89-107.
21. 2016. Creating a great spot for our teens! Greater Shepparton.[Accessed 28 March 2021].
22. Owens, P., 2002. No Teens Allowed: The Exclusion of Adolescents from Public Spaces. Landscape Journal, 21(1), pp.156-163.
23. Jansson, M., Abdulah, M. and Eriksson, A., 2018. s Urban Forestry & Urban Greening, 30, pp.115-123.
24. Van Hecke, L., Ghekiere, A., Veitch, J., Van Dyck, D., Van Cauwenberg, J., Clarys, P. and Deforche, B., 2018. Public open space characteristics influencing adolescents' use and physical activity: A systematic literature review of qualitative and quantitative studies. Health & Place, 51, pp.158-173.
25. Sensing Nature: Visual impairment and the natural environment. [Accessed 2 July 2021]
26. Public Workshop. [Accessed 2 July 2021]
27. London Legacy Development Corporation. Youth Space. [Accessed 2 July 2021]
28. Owens, P., 1988. Natural landscapes, gathering places, and prospect refuges: characteristics of outdoor places valued by teens. Children's Environments Quarterly, vol. 5, no. 2, 1988, pp. 17–24.
29. Plantlife, 2021. No Mow May. [Accessed 2 July 2021].
30. Plantlife, 2021. Cut less, cut later. [Accessed 2 July 2021]
31. HLF, 2016. State of UK Public Parks. [Accessed 2 July 2021].
32. Communities and Local Government Committee, 2017. Public Parks. The House of Commons. https://publications.parliament.uk/pa/cm201617/cmselect/cmcomloc/45/4502.htm [Accessed 2 July 2021]
33. Day, R. and Wager, F., 2010. Parks, streets and "just empty space": the local environmental experiences of children and young people in a Scottish study. Local Environment, 15(6), pp.509-523.
34. Phillips Lighting, 2021. Case study: Norwich Skate Park [Accessed 2 July 2021].
35. Public Art Online, 2021. Public Art Online Resources - Practical advice - Local authorities - Public Art and Local Authorities. [Accessed 2 July 2021].
36. Play Australia, 2021. Welcome to Play Australia [Accessed 2 July 2021].
37. Child in the City. Parks for teens, 10 features teens want to see [Accessed 2 July 2021]
38. British Youth Council.UK Youth Parliament. [Accessed 2 July 2021].
39. Groundwork, 2021. Kick the Dust: Future Proof Parks. [Accessed 2 July 2021]
40. Queen Elizabeth Olympic Park 2021. Legacy Youth Voice [Accessed 2 July 2021].
41. NHS England, 2020. NHS encourages children and young people to seek help as new data shows rise in mental health problems. [Accessed 2 July 2021].
42. White, M.P., Elliott, L.R., Taylor, T., Wheeler, B.W., Spencer, A., Bone, A., Depledge, M.H., Fleming, L.E., 2016. Recreational physical activity in natural environments and implications for health: A population based cross-sectional study in England. Prev Med 91, 383-388. doi:10.1016/j.ypmed.2016.08.023
43. Vivid Economics, 2017. Natural capital accounts for public green space in London. National Trust/HLF/Mayor of London, London. https://www.london.gov.uk/what-we-do/environment/parks-green-spaces-and-biodiversity/green-infrastructure/natural-capital-account-london [Accessed 2 July 2021]
44. Wheeler, W., Gordon Brown, H., Lovell, R., (2020) Making the Most of Green Space for People's Health. European Centre for Environment and Human Health, University of Exeter.[Accessed 2 July 2021]
45. Mitchell, G. (2019) The Messy Challenge of Environmental Justice in the UK: Evolution, status and prospects. Natural England Commissioned Reports, Number 273. [Accessed 2 July 2021]

Suggested citation:
Hind, K., de Bell, S., Lovell, R., Abrahams, R., Wheeler, B.W. (2021) More than just a skate park? A review and practical guide on how to make urban green space more accessible to adolescents to support health and wellbeing. South West Partnership for Environment & Economic Prosperity (SWEEP). www.sweep.ac.uk

This resource was produced as part of the SWEEP Investing in Nature for Health project. SWEEP is a partnership between the University of Exeter, the University of Plymouth and Plymouth Marine Laboratory. Funded by NERC, it brings together experts and stakeholders to solve key challenges faced by those working with our natural resources.

We thank Mary Coles at City College Plymouth, Jenny Carey-Wood at North Devon AONB and Dr Abigail Russell from the University of Exeter for review and feedback.

sweep
Investing in Nature for Health
RESOURCE

Understanding environmental investment for health in the South West – exploring dynamic mapping case studies

This report was produced in collaboration with our project partners.

Public Health Dorset

PLYMOUTH CITY COUNCIL

WWT

Why this matters

Current research confirms that natural environments provide benefits for physical and mental health; [1,2] and it is estimated that £2.2 billion of health benefits are generated in England per year due to people exercising in green and blue space. There is a corresponding, growing interest in harnessing these benefits to promote good health outcomes through nature-based interventions and activities. This is both at a national scale, such as improving access to the coast, and at a local level, with projects that are regenerating neighbourhood green spaces[3].

There are many challenges, however, to effectively delivering and sustaining such programmes. Attracting suitable investment into the environment for health, for example, is complicated due to the fact that funding often comes from a number of sources including government, corporate sponsorship, health and social care commissioning. Another key challenge is the need for cross-sectoral working, with successful programmes often requiring effective collaboration with a wide range of stakeholders from environmental management to public health.

Through our project partners, we understand that programme structures can quickly become complex and confusing, with disconnect arising between different funding streams, delivery partners and beneficiary groups. In order to meet the challenge of coordinating and balancing the priorities of these different interest groups, and to inform more streamlined cross-sectoral investments that increase health outcomes, there first needs to be a better understanding of current project structures, funding streams and stakeholder engagement. This resource responds directly to this need.

What is the purpose of this resource?

This resource introduces a method for mapping key stakeholder groups involved in nature-based health outcome programmes: their relationships, and the funding streams that sustain them. Three simplified maps have been produced focusing on specific case studies, detailing who is involved in investing in nature for health and how they are connected.

'I think the process of creating these maps with a group, and the discussion that ensues, is a really valuable part of this process'.

Zoe Sydenham, Natural Infrastructure Projects and Partnership Manager, Plymouth City Council.

The iterative process of creating these maps can enhance stakeholder engagement, understanding and co-operation. The maps themselves offer a visual aid to increase knowledge and understanding about current investment in the environment for health, helping to reveal some of the complexities and opportunities facing stakeholders. As such, they serve as a useful communication tool both within, and between, different stakeholder groups, whether practitioners or funders. By creating and displaying information in this way, it is also anticipated the maps will help to inform more strategic understanding, discussions, and decision-making.

Who should read this?

These maps, and the process of developing them, could be useful for any organisation who invests in, or is interested in investing in, the environment for health, as well as those that deliver nature-based health outcome projects. These might include local authorities, local government partnerships, charities, trusts, environmental managers, public health, and businesses.

References

[1] Houlden V, Weich S, Porto de Albuquerque J, Jarvis S, Rees K. *The Relationship between Greenspace and the Mental Wellbeing of Adults: A Systematic Review.* Vol 13.; 2018. doi:10.1371/journal.pone.0203000

[2] Twohig-Bennet C, Jones A. The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. Environ Res. 2018;166(June):628-6237. doi:10.15124/CRD42015025193

[3] Lovell R, Depledge MH. *Health and the Natural Environment: A Review of Evidence, Policy, Practice and Opportunities for the Future.*; 2018

The mapping process

Firstly, key organisations involved in the three case study programmes, and the connections between them, were identified using relevant publicly available resources e.g. programme websites, management group minutes, project reports. This information was entered into kumu.io – one of several free online tools which can be used to map relationships. The resulting maps were discussed with the stakeholders of each case study and the conversations were used to refine the maps and develop further understanding of the case studies. The maps have been developed to be easily modified in the future as projects and relationships between organisations evolve.

It is important to note that the maps included here are simplified versions of reality, representing just the key organisations and connections, and one point in time. To further enhance their value, additional connections could be added, as well as other potentially useful information such as the strength and quality of the relationships and types and amount of funding. This will help support a more in-depth analysis of the challenges and opportunities, links and synergies, both within and between different case studies.

The maps

This resource contains maps of three case studies:

1. Dorset Healthy Places
2. Plymouth Future Parks Accelerator
3. Wetland & Wildfowl Trust (WWT) Social Prescribing Scheme

Each case study categorises the following stakeholders:

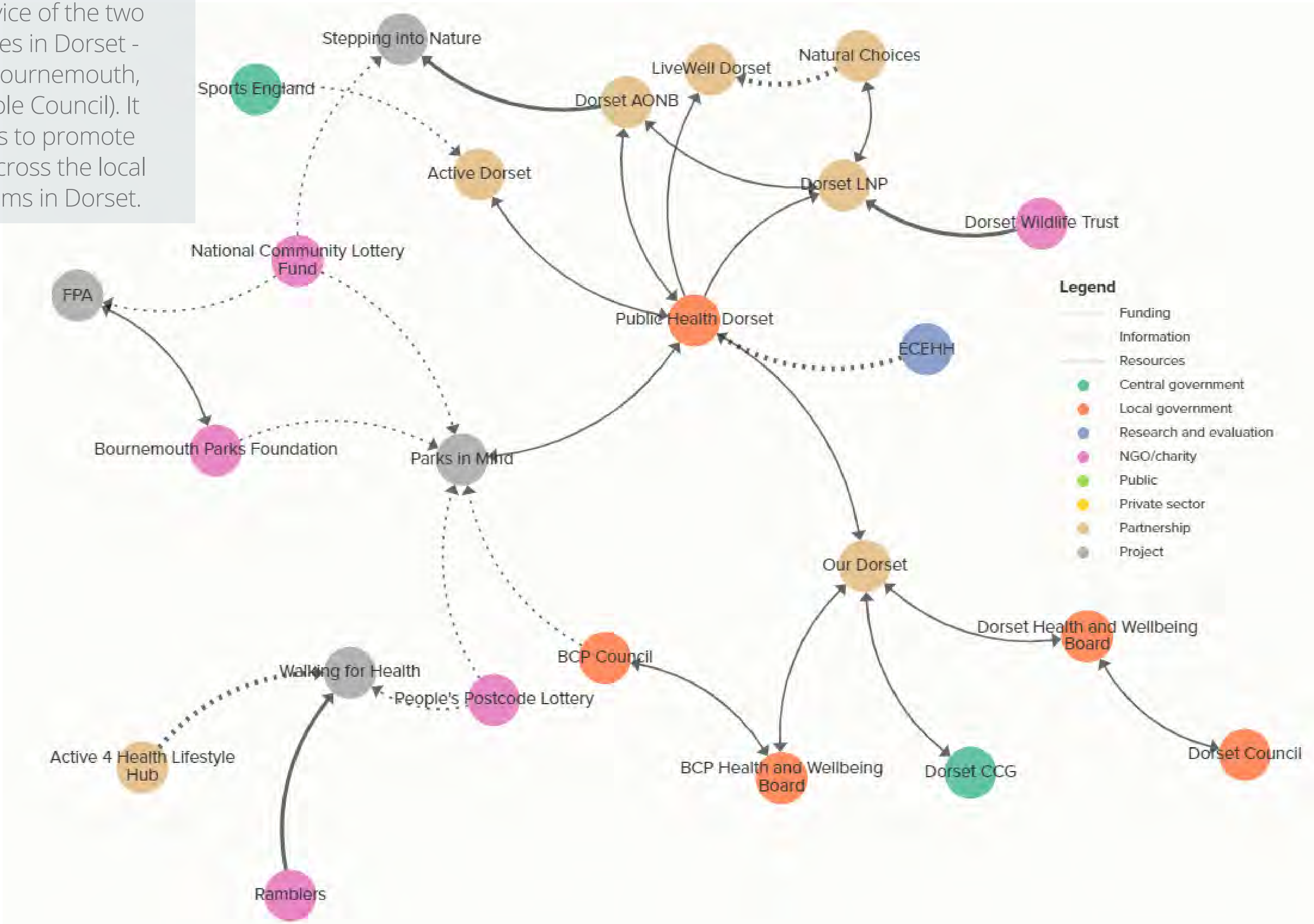
1. Central government
2. Local government
3. Partnership
4. NGO/charity
5. Private sector
6. Research and evaluation
7. Project

The maps also detail how these stakeholders are connected and the direction of the relationship:

1. Funding – the provision of monetary support.
2. Resources – the provision of non-monetary assets e.g., project management, site access.
3. Information – the provision of facts e.g., data.
4. Collaborative - multiple connections e.g., funding and resources between organisations.

Healthy Places Dorset

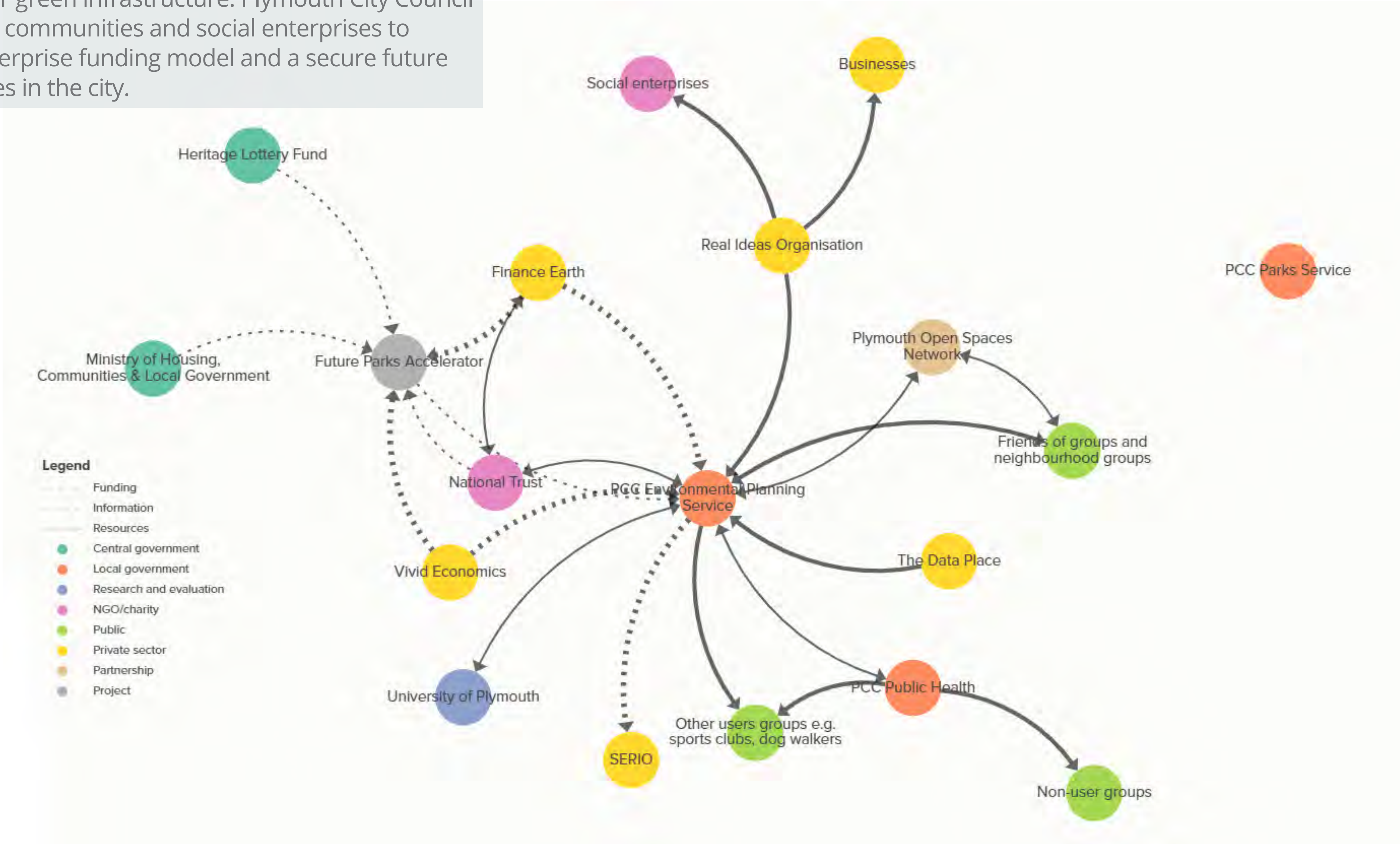
Healthy Places is a two-year programme led by Public Health Dorset (a shared service of the two unitary local authorities in Dorset - Dorset Council and Bournemouth, Christchurch and Poole Council). It is part of wider efforts to promote prevention at scale across the local health and care systems in Dorset.



Link to online kumu map for Dorset Healthy Places.

Plymouth Future Parks Accelerator (FPA)

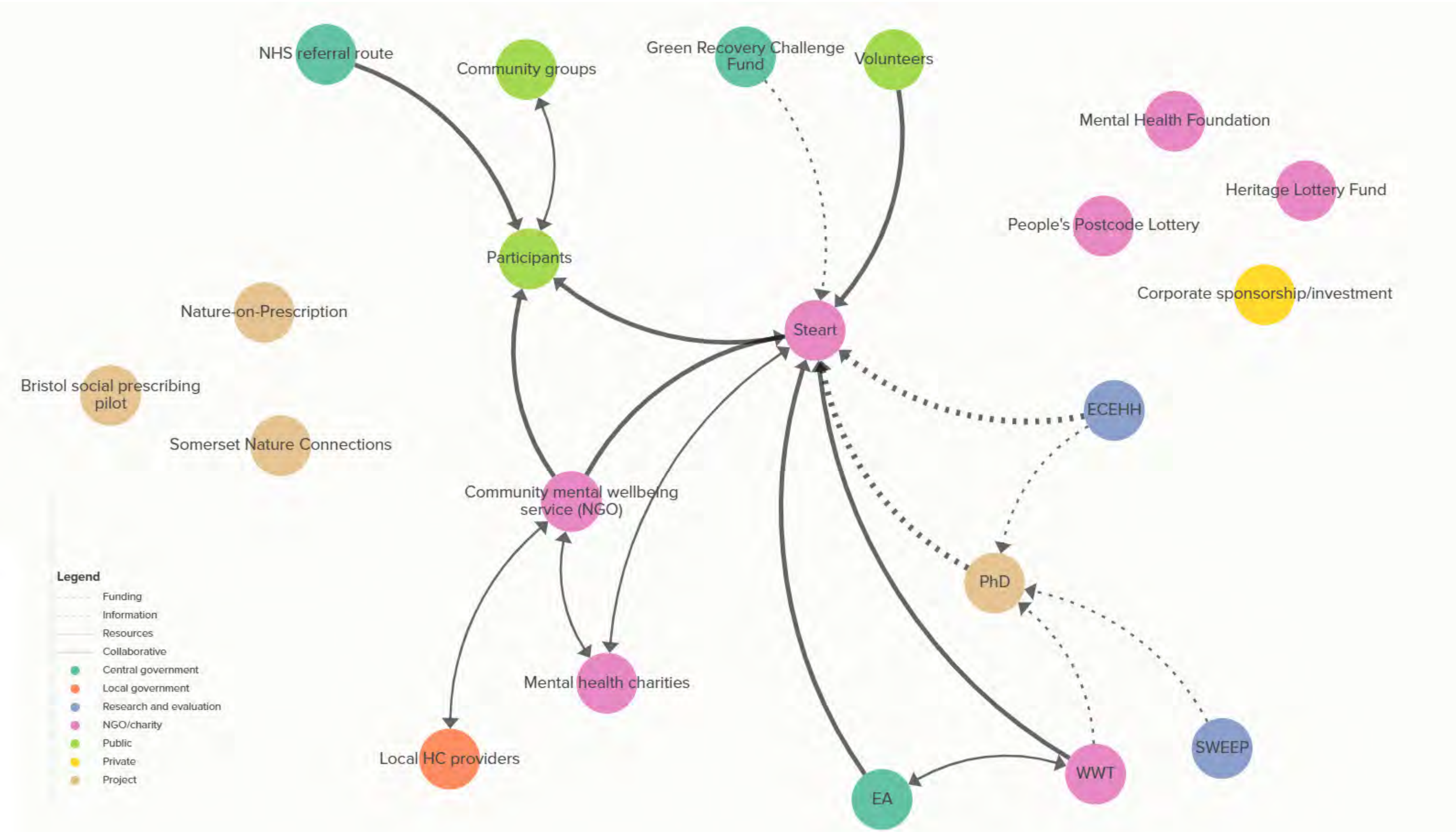
FPA is a collaboration between the National Lottery Heritage Fund, the National Trust and the Ministry of Housing and Local Government, providing grant funding, support, and advice. This two-year programme aims to enable local authorities to try new and innovative methods to manage their green infrastructure. Plymouth City Council is working with communities and social enterprises to develop an enterprise funding model and a secure future for green spaces in the city.



Link to online kumu map for Plymouth Future Parks Accelerator.

Wildfowl & Wetland Trust (WWT) Social Prescribing Scheme

Social prescribing links people to groups and activities in their community to support their health and wellbeing. WWT is working with local health care providers at their Steart site to implement a wetland-based social prescribing programme for people with low level mental and physical health conditions. The programme aims to encourage physical activity, connecting people with wildlife and social groups, within the wetland site.



Link to online kumu map for Wildfowl and Wetland Trust.

Conclusions

This approach is intended to support shared understanding of the complex connections between organisations across multiple sectors. In turn this can support the development and implementation of projects, programmes and partnerships that protect and improve the natural environment and human health and wellbeing. Through use of shareable, online tools, these maps can be dynamic and responsive, and the collaborative process of development may be as useful as the final map itself.

For example, the approach could be used to:

- Demonstrate impact of investment to external funders (with a 'before' and 'after' map showing additional stakeholders and connections)
- Communicate complexity of projects for evaluation
- Aid internal understanding of organisational relationships within projects
- Share project learning with other stakeholders
- Identify other stakeholders and funders for future work

Contact

For more information, see the SWEEP Investing in Nature for Health project at https://sweep.ac.uk/portfolios/investing-in-nature-for-health/ or contact the team via Ben Wheeler (b.w.wheeler@exeter.ac.uk)

Notes

This work was carried out with approval from the College of Medicine and Health Research Ethics Committee (reference Jul20/B/227/1).

De Bell, S., Hind, K., Abrahams, R., Lovell, R.& Wheeler, B. (2021) *Understanding environmental investment for health in the South West - exploring dynamic mapping case studies.* SWEEP resource, produced as part of the Investing in Nature for Health project.

SWEEP is a partnership between the University of Exeter, the University of Plymouth and Plymouth Marine Laboratory.

Funded by NERC, it brings together experts and stakeholders to solve key challenges faced by those working with our natural resources.

European Centre for Environment & Human Health

NERC SCIENCE OF THE ENVIRONMENT

sweep

Policy for Pollinators RESOURCE

Wildflowers: A business case for engagement, environment and economics

Highlighting the potential opportunities and benefits of wildflower seed production in Cornwall and the Isles of Scilly

The Lost Gardens of Heligan

BEE-STEWARD

Image © Alasdair Moore, 2022. The Lost Gardens of Heligan Wildflower Project; a stunning 15 acre annual meadow providing a unique visitor attraction and generating £18K worth of seed.

"Cornwall's biggest industry is tourism… let's make Cornwall the most beautiful, wildflower laden, glorious place to visit in the country!"

Alasdair Moore, Head of Gardens and Estate, The Lost Gardens of Heligan.

The Business Case - why wildflowers?

What is this report and who should read it?

Drawing on the Heligan Wildflower Project case study, this resource outlines a wider business case for the potential opportunities and benefits of local wildflower seed production. It will be of interest to any landowner, land manager, environmental practitioner or policymaker interested in how the production of local wildflower seed can boost local businesses, enhance biodiversity and increase the health and wellbeing of residents and visitors to Cornwall and the Isles of Scilly, and beyond.

The opportunity

There is a significant and growing demand for locally sourced wildflower seed in the South West of England. This is seen across farming, business, conservation and local government sectors. For example, local and parish councils are creating wildlife-friendly greenspaces, farmers and landowners are planting wildflower meadows and margins and re-wilding estates, and innovative businesses are developing new products from wildflower seed to diversify their income.

This demand is only likely to increase following the Government's 2020 Green Recovery Plan, incentivising the protection and restoration of nature (e.g. new agri-environment schemes [1]) to benefit business, the environment and people's health and wellbeing.

The majority of wildflower seed used for these activities to date has been harvested either from a limited number of donor sites, or bought from national commercial seed companies. Therefore, an exciting opportunity is emerging for businesses to pioneer novel locally produced wildflower seed products and services. These have the potential to boost and diversify income, whilst at the same time enhancing the natural environment, and bringing together both local communities and visitors for enhanced health and wellbeing.

Decline in wildflowers and pollinators

There is currently high demand for wildflower seed, especially for species-rich meadow seed mixes. However, having lost 97% of lowland meadows since WWII[2], this valuable resource is now in short supply. Pollinators that pollinate wildflowers and crops are also under threat, with one third of wild bee and hoverfly species in decline in the UK[3].

> "Everything we do at Cabilla has to be ecologically, economically and spiritually sustainable. Planting wildflower seeds for pollinators and for guests to walk through ticks all three of those boxes."

Merlin Hanbury-Tenison,
Founder,
Cabilla Cornwall

Engagement

People

For every £1 spent on projects enhancing nature, between £6.88 - £8.50 is returned in health and wellbeing[4] benefits. Wildflowers offer novel community and visitor engagement opportunities.

Environment

Planet

The pollinating work of wild bees is worth over £2.4K per hectare of crop[5]. Protecting, and creating new flower-rich habitats is key to ensuring our valuable pollinators thrive. Wildflowers provide nectar and pollen for pollinators, support biodiversity, capture carbon and enhance natural capital.

Economics

Profit

Customers will pay more for environmentally locally produced products. Wildflowers offer new opportunities through selling of the seed, creating new products and services and attracting visitors.

Wildflowers

Case Study – The Heligan Wildflower Project

The Lost Gardens of Heligan [6]

This is a 200 acre garden and estate in Cornwall, South West of England. The Heligan Wildflower Project was designed and managed by Alasdair Moore (Head of Gardens and Estate at Heligan), working closely with Richard Scott from the National Wildflower Centre[7]. See the full Heligan Wildflower Project case study for more details.

The Heligan Wildflower Project benefits

Since 2019, a large 15-acre meadow has been successfully established with cornfield annuals on the Lost Gardens of Heligan site. This delivers multiple benefits including an unforgettable visitor experience, plentiful food for pollinators and additional business income. This project provides an excellent case study of business enhancement through the growing of wildflowers.

The costs

The initial 87kg of seed mix, including Poppy (*Papaver rhoeas*) (seed treated), Cornflower (*Centaurea cyanus*), Corn marigold (*Glebionis segetum*), Corn chamomile (*Anthemis arvensis*) and Corn cockle (*Agrostemma githago*) was bought from the National Wildflower Centre, based at the Eden Project in Cornwall. This consisted predominantly of poppy seeds in reference to the First World War commemorations at Heligan over the previous four years.

The poppy seed was costly (£7,000), as it had been treated to increase its germination. Labour and machinery hire for preparing the ground, sowing, harvesting and cleaning the seed cost £2200, and design and printing of seed packets for retail cost £1,154. Other wildflower planting projects could significantly reduce this initial outlay cost by either reducing, excluding, or replacing this with a lower cost seed (i.e. seed mix excluding poppy cost £2,830).

The returns

In the first year (2019), 153kg of seed was available for wholesale and retail once the harvested seed was cleaned and separated by Emorsgate[8] (the leading national wildflower seed company). Bulk wholesale price was between £60/kg and £100/kg, which meant that Heligan had between £9,180 and £15,300 worth of seed at wholesale value.

However, Heligan was also interested in the opportunity to retail its seeds via wildflower seed packets in its shop. Seeds grown on-site offer a highly marketable product providing a higher retail revenue of £389.56/kg (in Heligan's case sold singularly in 7g packets, with a multi-buy discount).

Thus, Heligan adopted a model of part wholesale (83% of the seed being sold back to the National Wildflower Centre) and part retail (17% of the seed selling in the Heligan shop). This model shows an approximate **gross income of £17,749 in the first year** and, after costs, a net income of £11,565 - representing a 187% return on investment.

Table 1 shows this, along with a predicted forecast based on this model over five years, using the lowest wholesale price of £60/kg and excluding poppy seed. On this basis, a 389% return on investment is predicted by year five.

Alastair's vision:

- Draw in visitors and revenue.
- Communicate with the public about flowers and pollinators.
- Produce saleable crop products e.g. wildflower seed.
- Act as a test-case / exemplar for the potential of local wildflower seed production.

Table 1
The estimated five-year forecast for a 15-acre site based on the Lost Gardens of Heligan's Wildflower Project results from year 1.

Year	Year 1	Year 2	Year 3*	Year 4	Year 5
Costs:	**£6,184**	**£3,421**	**£4,078**	**£3,559**	**£3,631**
Seed	£2,830		£589		
Labour	£2,200	£2,244	£2,289	£2,335	£2,381
Seed packets	£1,154	£1,177	£1,201	£1,225	£1,249
Gross Income:	**£17,749**	**£17,749**	**£17,749**	**£17,749**	**£17,749**
Wholesale **	£7,620	£7,620	£7,620	£7,620	£7,620
Retail	£10,129	£10,129	£10,129	£10,129	£10,129
Total net Income:	£11,565	£14,327	£13,670	£14,189	£14,118

* an optional 20% over-seed in year 3 ** using the lowest wholesale price of £60/kg

Other potential returns on investment

- ✓ **Increased visitor numbers and repeat visits -** our 2021 visitor survey data confirmed that 79% would visit again to experience the meadow, and 90% would recommend visiting the meadow to someone else.

- ✓ **Enhanced biodiversity and pollinator numbers -** wildflower meadows deliver numerous valuable ecosystem services such as carbon sequestration and pollination. The latter, provided by wild pollinators attracted to wildflower meadows, could be worth over £2.4k per hectare of crop[5].

- ✓ **Health and wellbeing benefits -** there are various economic and non-economic measures and tools for evaluating the health and wellbeing benefits of nature based health interventions used to assess the value of this ecosystem service, one of which suggests returns of between £6.88 - £8.50, for every £1 spent. In Heligan's case, this could mean that with an initial investment of £6,184, health and wellbeing returns could be between £42,546 - £52,564, but only if nature-based activities, such as social prescribing, were run in conjunction with the wildflower site.

> "In all my thirty years of horticulture, the Heligan Wildflower Project is unquestionably my favourite project. Regardless of age group or background, everyone was moved by what they saw"

Alasdair Moore, Head of Gardens and Estate, The Lost Gardens of Heligan

2022 Update from Heligan

A similar yield and return were expected in the years following 2019. However, 2020 brought the Covid-19 pandemic and with it, unforeseen challenges, one of which was a very restricted cash flow. As a result, Heligan departed from their year 1 model, agreeing instead, to give their wholesale seed to the National Wildflower Centre in exchange for their ground preparation and harvesting services. Heligan also paid for on-site seed cleaning by South West Seeds (£500). In year 2, therefore, Heligan's only income stream was from their retail seed sales – a reduced, but non-the-less, vital source of much-needed cash.

In 2021, there was an unusually dry spring which resulted in a much less diverse display of wildflowers. Consequently, Heligan decided not to harvest their seed, instead taking the opportunity to revise their plans and develop a perennial and annual wildflower seed project for 2022.

It is important to note, therefore, that Table 1 outlines the potential business opportunity for wildflower seed production based on Heligan's year 1 model (and results) being replicated in subsequent years. The factors above explain why this has not been possible at Heligan, and therefore the model does not reflect the actual year 2 and year 3 returns of the Heligan Wildflower Project.

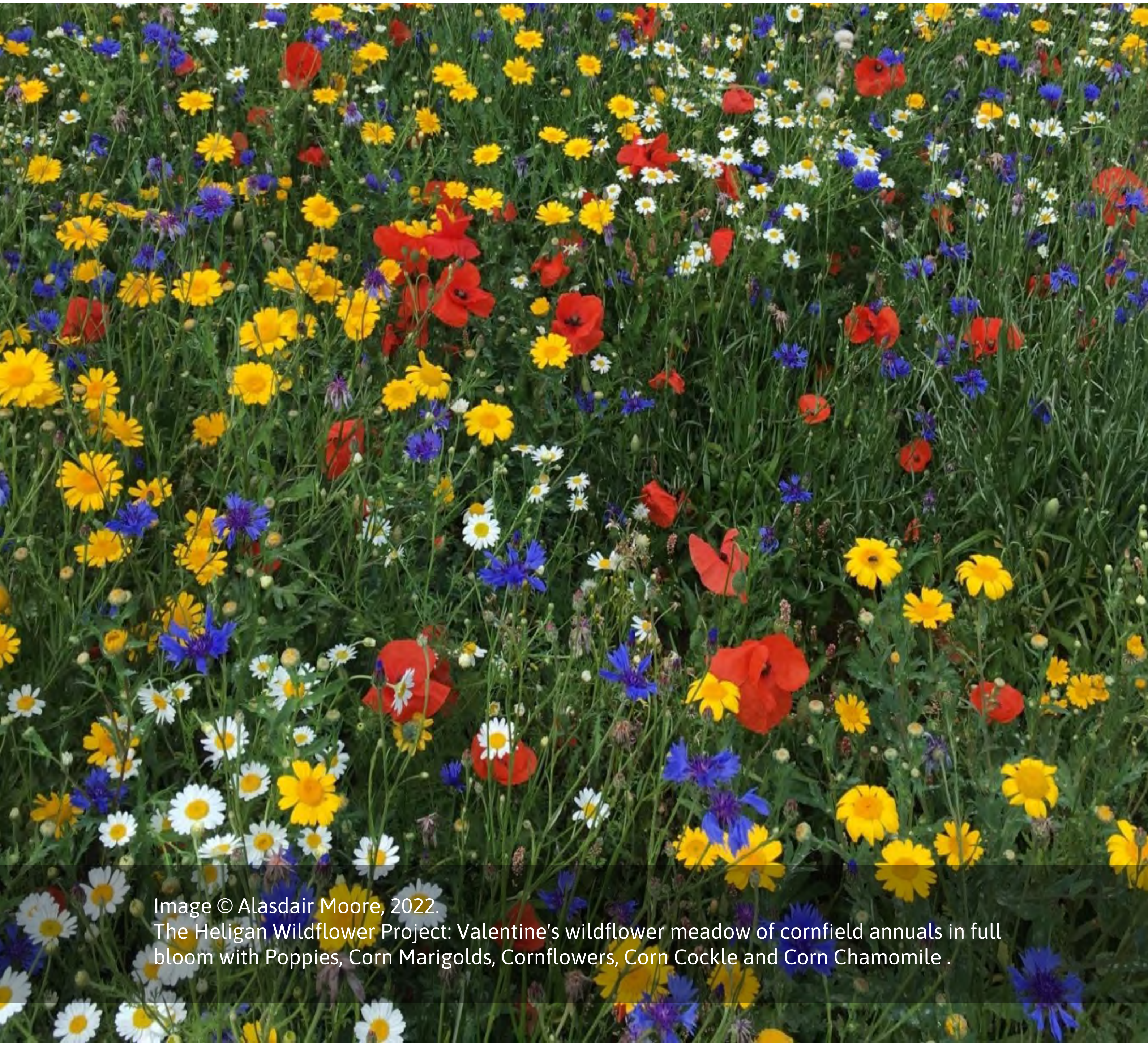


Image © Alasdair Moore, 2022.
The Heligan Wildflower Project: Valentine's wildflower meadow of cornfield annuals in full bloom with Poppies, Corn Marigolds, Cornflowers, Corn Cockle and Corn Chamomile .

Wildflowers for your business

The Heligan Wildflower Project has provided a valuable learning experience for the team at the Lost Gardens of Heligan. It is also beginning to inspire other landowners looking to plant wildflowers and adopt similar wholesale and retail business models to realise the opportunities for economic, social and environmental returns.

The lessons learnt from this project will be invaluable to others embarking on similar ventures, for example, ensuring sufficient time and investment to establish product differentiation, brand development and marketing to highlight the unique local "Cornish" and "Isles of Scilly" elements. Additionally, this project highlights the importance of setting up a successful retail market and collating and communicating the evidence about the positive local community and environmental benefits of growing wildflower meadows. This investment and work could be undertaken in collaboration with other interested businesses, such as the Lost Gardens of Heligan, to ensure cost-efficiencies.

There is also growing demand for wildflower seed sourced from local provenance perennials (plants that live for several years) for habitat regeneration, longer-term carbon storage and natural capital enhancement projects.

This offers a further opportunity for landowners, conservation organisations, and volunteers to work together to locate, protect, and enhance local perennial wildflower seed sources and ensure the seed is sustainably and effectively collected, sown, and harvested. As we've seen, the Lost Gardens of Heligan already plan to create perennial wildflower displays in the future.

The benefits

Examples of potential wildflower products and services:

- Wholesale seed for land regeneration and nature recovery, e.g. agri-environment scheme options.
- Wholesale seed for community greenspace development and green infrastructure.
- Retail for households, community projects and schools.
- Nutraceutical oils from calendula, borage and sunflower seeds (in collaboration with Trelonk).
- Wildflower turf or seed balls.
- Natural dye from wildflower petals/roots.
- Specialist conservation mixes and wild birdseed.

Planting wildflower meadows offers a range of unique business opportunities that also benefit the environment and people and include:

Business diversification and resilience - the creation of new products and services (see above) and high-quality grass-fed beef, lamb and dairy products from livestock grazing on perennial wildflower meadows.

Cost savings - wildflower areas provide ground cover that reduces weeds and disease (requiring fewer chemicals), increase protein and minerals in forage for livestock (resulting in healthier livestock) and, where wildflower areas include legume species such as clovers, fix nitrogen from the air (providing free fertiliser).

Supporting biodiversity - wildflowers provide food and habitats for pollinators and other beneficial insects.

Action against climate change - regeneration of land to create wildflower meadows improves soil structure, reduces water run-off and flooding, and sequesters carbon – all of which reduces our carbon footprint[9]

Health and wellbeing - wildflower meadows offer local communities and visitors an opportunity to engage and connect with nature, thus enhancing physical and mental health. Good health and high wellbeing is associated with spending at least 2 hours a week in nature[10,] and the psychological benefits increase with increased biodiversity of green spaces[11]. For more research and resources on the link between nature and health and wellbeing, visit the SWEEP Investing in Nature for Health Hub and project webpage.

Conclusion

This business case study illustrates how wildflowers can form part of a sustainable business model that aims to boost and diversify income (contributing to the local economy of Cornwall and the Isles of Scilly), whilst at the same time enhancing biodiversity, and people's engagement with, and benefit from, nature. We advise that businesses looking to take inspiration from this business case study and interested in exploring the opportunity further should seek independent advice from their financial advisor and agronomist.

Wildflowers could form a sustainable part of your business plan if..

- Used as part of a broader business model around enhancing the natural environment and visitor experience.
- Based on a blended model of seed for retail and wholesale.
- Due consideration is given to the impact of unforeseen circumstances affecting yield and/or cash flow.
- There is considerable investment in developing the brand and product differentiation.
- The business aims to benefit from economies of scale by partnering with other businesses to share land, expertise, personnel, machinery, equipment and a branding and marketing strategy.
- The business explores opportunities and partnerships to create new products from the seed.
- There is a collaboration between wildflower businesses and conservation/ wellbeing organisations.
- Seed collection and production are conducted in a way that enhances the natural environment.
- The business initially focuses on annual species before exploring opportunities for perennial seed.

For those with land, investing in seed, labour, harvesting and branding and marketing for wildflower products could have the potential to return £11-£14K pa whilst also providing benefits for people, the planet and profit.

References

[1] The Environmental Land Management scheme: an overview - GOV.UK (www.gov.uk)

[2] Fuller (1987), Biological Conservation, 40, 4.

[3] Powney *et al.* (2019), Nature Communications, 10, 1.

[4] SROI Report FINAL - DIGITAL.pdf (wildlifetrusts.org)

[5] Kleijn *et al.*, (2015), Nature Communications, 6, 7414. This is a US study but provides a proxy for the ecosystem service of pollination from wild pollinators. This paper combines USA and European results on the contribution of wild pollinators to a range of crops. $3,251 per ha converted to £2,480 per ha using the exchange rate at time of writing.

[6] The Lost Gardens of Heligan

[7] National Wildflower Centre at the Eden Project, Cornwall

[8] Emorsgate Seeds (wildseed.co.uk)

[9] Carbon storage by habitat- NERR043 (naturalengland.org.uk)

[10] White *et al.* (2019), Scientific reports, 9, 7730

[11] Fuller *et al.* (2015), Biology Letters, 3, 4

For further information, please contact:
Dr Grace Twiston-Davies, University of Exeter,
g.twiston-davies@exeter.ac.uk

June 2022.

The South West partnership for Environmental and Economic Prosperity (SWEEP) helps deliver economic and community benefits whilst also protecting and enhancing the area’s natural resources.

Citation: Twiston-Davis, G., Abrahams, R., (2022). *Wildflowers: a business case for engagement, environment and economics.* This SWEEP resource was produced from the Policy for Pollinators project, part of the South West Environment and Economic Prosperity (SWEEP) programme.

SWEEP is a partnership between the University of Exeter, the University of Plymouth and Plymouth Marine Laboratory. Funded by NERC, it brings together experts and stakeholders to solve key challenges faced by those working with our natural resources.

Habitat Classification and Change Detection Tools

Availability: These data are currently available on request from Naomi Gatis N.Gatis@exeter.ac.uk . Following publication in an accompanying journal, the tools and maps will be freely available online.

The Habitat Classification Tool

This tool enables consistent, and annually repeatable, mapping of habitats across the extent of Dartmoor National Park, not possible by previous field survey methods. It improves on current data provision by providing time series data that is easily updated and delivers a comprehensive baseline habitat data against which change can be detected.

The tool uses pixels of known habitat class to train a random forest classifier, with freely available Sentinel-2 satellite imagery combined with LiDAR data products (slope, aspect and elevation), to predict the most likely habitat class for each pixel across the mapped Dartmoor National Park area. It also provides measures of accuracy which enables the user to acknowledge the uncertainties within the map and therefore have an appropriate level of confidence in the mapped habitats.

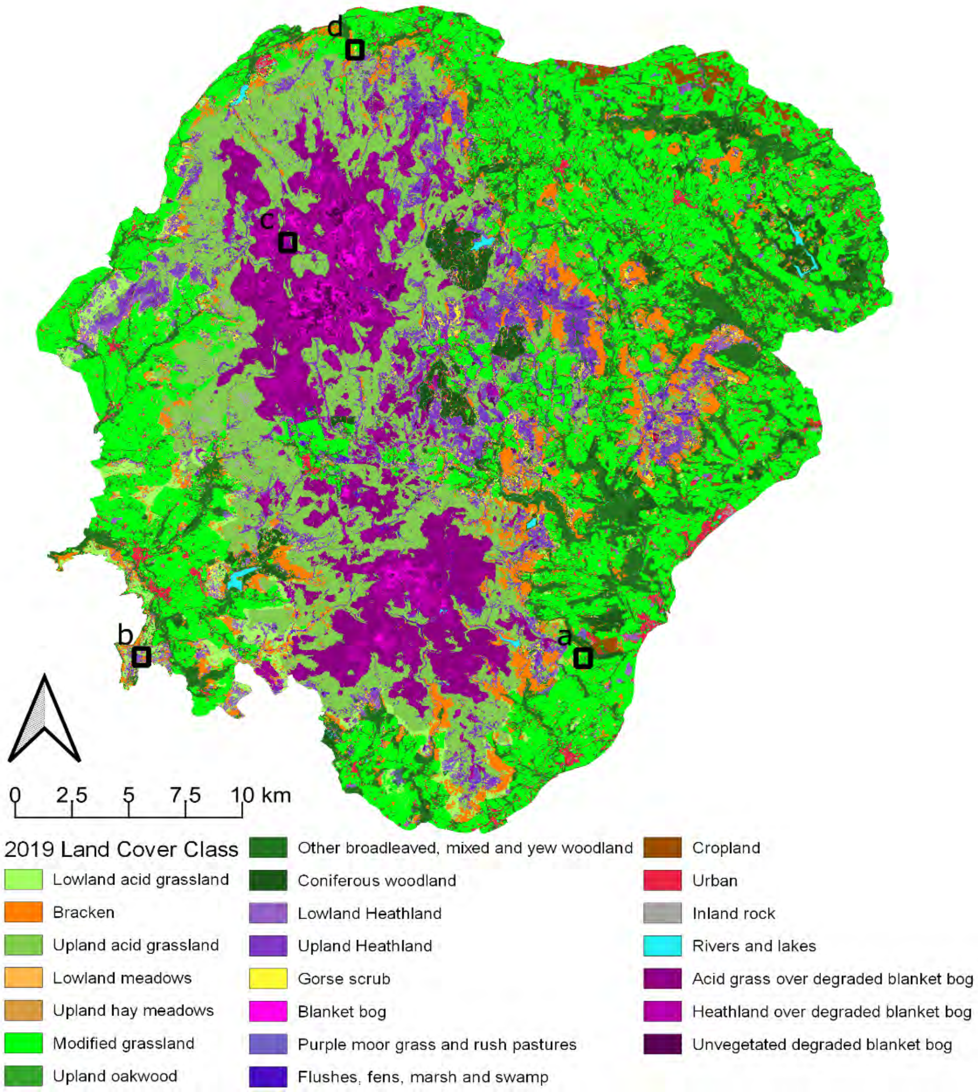


Fig 1. Mapped UKHab Classes across Dartmoor National Park for 2019. Boxes (a)-(d) relate to the images in Fig 2.

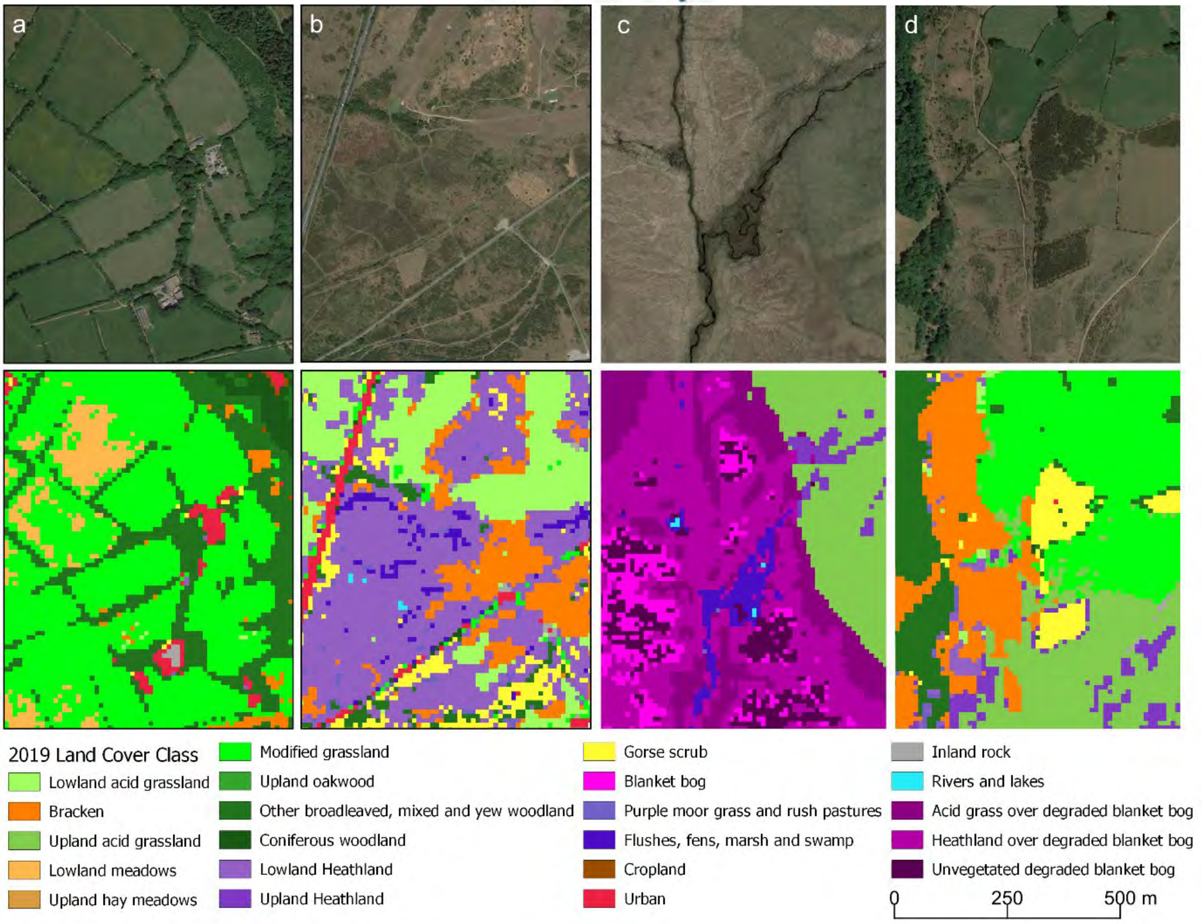


Fig 2. 1:10000 scale images showing examples from Dartmoor National Park of (a) mapped lowland habitat types including Lowland meadows (b) the complex mosaic of fragmented habitats captured in semi-natural areas (c) the variation in vegetation cover overlying degraded blanket bog (d) Gorse and Bracken encroachment on the moorland fridge. Aerial Imagery ©2021 Google.

THaW (Tree, Hedgerow and Woodland) Mapping Tools

Availability

If you are interested viewing or using either the **THaW Mapping Dataset** or the **THaW Change Detection tool** for non-commercial use, please contact Dr David Luscombe (d.j.luscombe@exeter.ac.uk).

The THaW Mapping Toolbox – This Toolbox autonomously and rapidly generates high resolution, baseline THaW maps, across landscape extents, using 2m^2 LiDAR Data and bespoke data processing approaches. See figure 1 for example outputs.

Fig 1: Screenshot from the Tree Hedgerow and Woodland (THaW) mapping and change detection tool showing an example from a mixed agricultural/urban extent in North Devon, UK. The coloured pixels correspond to the classes of tree and woodland defined in the legend. Small areas of woodland, mature and managed hedgerow, and individual /emergent mature trees, can all be seen within this relatively small extent.

The THaW Change Detection Tool

Drawing on THaW mapping data and spaceborne radar data, this tool adds an online platform which can autonomously detect changes to the mapped THaW habitats, through time. Using Sentinel I synthetic aperture radar (SAR) data, this tool enables remotely sensed canopy change detection to be mapped for any calendar quarter selected by the user, enabling close to real time tracking of canopy loss and woodland management. See figure 2 for example outputs.

Fig 2: Screenshot from the Tree Hedgerow and Woodland (THaW) mapping and change detection tool showing an example from a mixed agricultural extent in North Devon, UK. The red area, on the right-hand side of the image, highlights an area of canopy loss automatically detected during the 1st quarter of 2021. Such change is automatically derived using user defined time periods and detected using composite multitemporal satellite-borne radar (SAR) data.

Coastal Change Management Areas: A new methodology

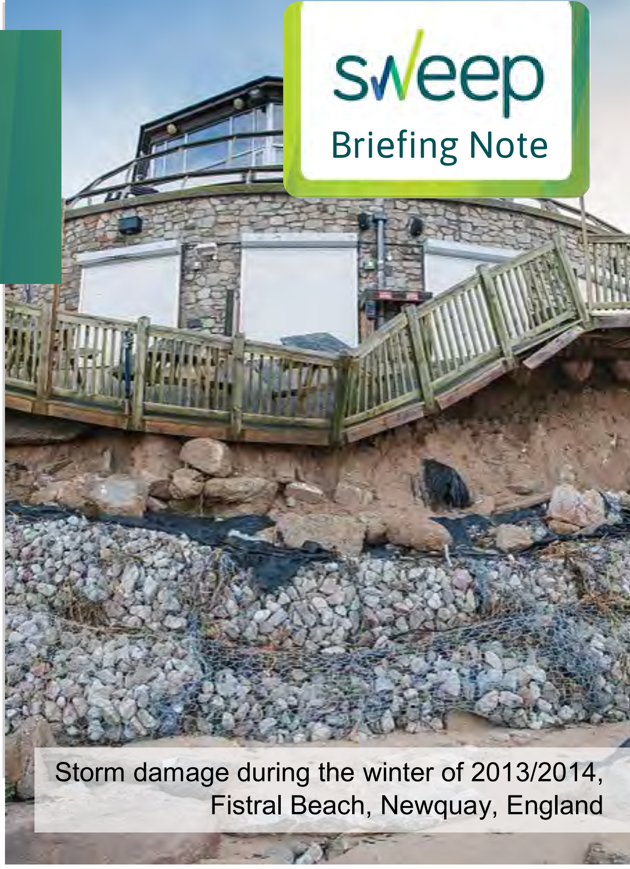
A Case study with Torridge, North and East Devon Local Planning Authorities

sweep
Briefing Note

This briefing note provides an overview of a new, scientifically-robust methodology designed to support Local Planning Authorities demarcate Coastal Change Management Areas (CCMAs) which significantly improves on previous guidance.

The methodology was successfully trialled on the Taw-Torridge Estuary (North Devon) and around Sidmouth (East Devon) before being recommended for inclusion in Local Plans, as 'materials consideration' for coastal planning and engineering decisions, and used to extend CCMA mapping for the whole of these coastline areas.

This work was undertaken as part of the NERC-funded SWEEP programme (South West Partnership for Environment and Economic Prosperity). Full details of the project and methodology can be found on the SWEEP website.



Storm damage during the winter of 2013/2014, Fistral Beach, Newquay, England

CCMA: An area identified within Local Development Plans as likely to be affected by physical changes to the shoreline through erosion, coastal landslip, permanent inundation or coastal accretion.

Who should read this?

- Local Planning Authorities
- Coastal Management Policy makers
- Risk Management Authorities (RMAs)

Why does this matter?

With the UK coastline retreating up to a metre every decade due to erosion, landslips, flooding and shifting sediments, Local Planning Authorities (LPAs) have the difficult task of managing future developments along these unstable coastal and estuarine margins.

To address these issues, the UK's National Planning Policy Framework requires LPAs to identify where shorelines are likely to change significantly over the next 100 years. These designated Coastal Change Management Areas (CCMAs) can then be used to inform planning and management decisions.

> *"The SWEEP approach was invaluable in bringing all key stakeholders including the Environment Agency and Natural England to shape and move CCMA work forward and increase our confidence in this area."*
>
> **Ian Rowland, Senior Planning Officer, Torridge District Council**

LPAs, however, often lack the confidence, in-house expertise, or consistent methodology to establish such designations. This means that very few CCMAs currently exist, and coastal development continues in active coastal zones with little regard for future shoreline shifts.

In response, SWEEP scientists worked with a range of project partners to develop a new scientifically robust method that planners could adopt, the public understand, and which improved upon existing guidance by incorporating the latest climate science. This was trialled in Sidmouth, East Devon (a coastal wave-dominated environment prone to erosion) and the Taw-Torridge estuary, North Devon (a tide-dominated environment impacted by flooding).

The output was a clear, concise methodology for use by any LPA, which could deliver the underlying science needed to support the process of designating CCMAs.

> *"Information from the SWEEP CCMA mapping is helping us to take a new approach to an adaptive pathway, thus strengthening our submission."*
>
> **Chris Wilson, Coastal Engineer, Torridge District council**

Methodology for CCMA demarcation

The methodology below presents a robust, transparent, repeatable approach that can be undertaken using publicly available data.

Coastal types

Sandy beaches | gravel barriers | cliffs | estuaries

Data required

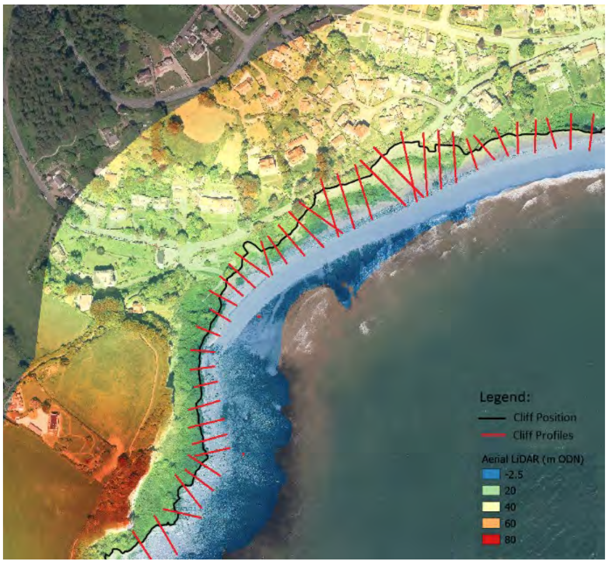
- Current shoreline position
  e.g. cliff top, high-water line or barrier crest
- Historic sea-level rise (SLR) rate
- Future sea-level rise (SLR) predictions

Approaches

1. Cliffs	Derive historic retreat rates either through volumetric analysis of cliff profiles using two LiDAR datasets or using historic mapping to measure cliff top change. Apply predicted SLR to calculate the predicted future retreat rates to compute projected cliff position. Alongshore smoothing of the new cliff lines is required to manage the spatial variability in retreat rates caused by the episodic nature of cliff loss.
2. Beaches (sand/gravel)	Use the average cross-shore profile to calculate beach response under future SLR. This approach assumes profile shape will remain through landward migration of the beach.
3. Barriers	Derive historic retreat rates from historic mapping, aerial imagery or LiDAR by using barrier crest as a reference point. Apply barrier roll-back method using barrier volume to calculate barrier retreat under future SLR.
4. Estuaries	These environments are tide dominated and not exposed to significant erosion. CCMA mapping needs to consider future inundation extents by mapping projected flood levels onto current LiDAR digital elevation maps
5. Defended Coasts	Existing coastal defences make it very difficult to forecast shoreline change under SLR. Assumptions can be made that ignore defences (using methods above) but are likely to be unrealistic. All of this work can be undertaken within a GiS platform or Python/Matab software.

Output Mapping

CCMA mapping can be split into epochs to match Shoreline Management Plan outputs e.g. 20, 50 and 100 yrs. Where possible a 'buffer' or 'probabilistic' approach should be adopted to help convey the uncertainty inherent in the projected SLR rates.



Aerial imagery overlaid with LiDAR mapping, cliff position and cross-shore profiles.

Projected future cliff position for different epochs; buffers allow uncertainty to be visualised.

To find out more see the SWEEP website or contact Dr Tim Poate timothy.poate@plymouth.ac.uk
Published September 2022.

sweep | UKRI Natural Environment Research Council | Natural England | Environment Agency

SWEEP Regional Development Resources (RDRes) for Local Government

Evidencing the role of Natural Capital as a driver towards economic prosperity and societal benefit

This SWEEP Resource Pack provides evidence, information and tools to support the role of Natural Capital as a driver towards economic prosperity and societal benefit.

It has been designed for local councils and other organisations in the South West to aid preparation of Business Cases, development of Local Plans, implementation of policies and preparation of new initiatives or projects. It draws from across SWEEP's wide-ranging portfolio of 35+ projects and includes information about reports, tools and approaches developed under SWEEP.

The SWEEP project **(South West Partnership for Environment and Economic Prosperity; 2017-2023)** aimed to bring natural capital and environmental considerations into the heart of the decision-making in the South West. SWEEP provided a regional exemplar of how the 'Natural Capital Approach' can be adopted at scale. It helped to deliver this approach by co-creating guidance, tools and solutions with a diverse range of project partners. Please view our film to learn more about the SWEEP approach.

SWEEP's portfolio of interlinked Impact Project was co-designed with over 300 partners from business, policy or community sectors. SWEEP academics and Impact Fellows worked in close collaboration with these partners to realise environmental, economic and/or community benefits for the South West region and beyond. We also advanced early research careers through supporting a range of diverse PhD studentships.

For more information about these resources please **use the hyperlinks**. For other enquiries please email **sweep@exeter.ac.uk** To view SWEEP's legacy website and our series of 35+ Project Impact Summaries please visit **www.sweep.ac.uk**

SWEEP resources for local government

Subject	Resources	Summary
Nature-based Health and Well-Being Best practice for the planning, financing, delivery, monitoring and evaluation of green and blue spaces for health and wellbeing.	Making the most of green space for people's health	Guidance on how green space benefits health and can be improved, expanded and promoted to maximise benefits for people and the environment.
	Improving access to green space: A new review for 2020	Evidence and recommendations on the equitable provision of greenspaces for communities.
	Review of health and wellbeing evidence for the green infrastructure standards	Summary of evidence on how green space supports health and wellbeing.
	Alternative funding mechanisms for green space	Alternative mechanisms for funding green space beyond local authority provision, including case studies of successful use.
	More than just a skate park? A review and practical guide on how to make urban green space more accessible to adolescents to support health and wellbeing	Drawing on the latest evidence from across the world, a review and practical guide on how to make urban green space more accessible to adolescents to support health and wellbeing.
	Nature on prescription Handbook	Evidence and suggestions on how Nature on Prescription can support people's mental health and how to deliver a high-quality scheme.
	Evaluating interventions in green space: Derriford Community Park	An evidence-based resource using causal loop diagrams to show links between greenspace interventions and health benefits, highlighting key factors for success and evaluation measures.
	Understanding environmental investment for health in the southwest – exploring dynamic mapping case studies	Looking at three cross-sectoral health focused projects in the South West, this explores stakeholder's connections, revealing opportunities and challenges

	A Five Capitals Model approach – building a business case for investment in nature for health Supporting case studies for the 'A Five Models approach' resource	Demonstrating how the Five Capitals Model approach, backed by relevant evidence, can provide a convincing and credible framework for strengthening such a business case, placing Natural Capital at the centre of interest.
	Economic and Non-Economic Measures and Tools – Evaluating the health and wellbeing benefits of nature based health interventions – Supporting case studies for the 'Economic and Non-Economic Measures and Tools' resource.	Presenting and analysing case studies, and drawing on the latest evidence, to provide details about some of the most commonly used economic and non-economic measures and tools for measuring, and quantifying, the success of investments in the environment for health.
Quantitative Habitat mapping Mapping habitat cover using satellite and LiDAR data	Habitat Classification tool and Habitat Change Detection tool	The Habitat Classification tool enables consistent, and annually repeatable, baseline mapping of habitats across the extent of Dartmoor National Park, not possible by previous field survey methods. The Habitat Change Detection tool detects and maps change over time in the habitat classes within Dartmoor National Park.
Tree Hedgerow and Woodland (THaW) mapping Mapping woodland cover using satellite and LiDAR data	THaW tools	First of its kind, the THaW Mapping Toolbox autonomously and rapidly generates high resolution, baseline maps, across landscape extents, using 2m2 LiDAR Data and bespoke data processing approaches. The THaW Change Detection autonomously detect changes to the mapped THaW habitats over time.
Enhancing pollinator-friendly land management practices	BEE-STEWARD model	This cutting-edge computer software tool helps farmers and land managers see how pollinator-friendly management on their farm could affect bee survival and pollination rates.

Predictive tool, wildflower seed Business Case, seed swapping Collective.	The Lost Garden of Heligan Wildlflower Business Case	An innovative business case highlighting the potential opportunities and benefits of wildflower seed production in Cornwall and the Isles of Scilly – now inspiring other land owners across and beyond the SW.
	Lost Gardens of Heligan case study for growing and harvesting wildflower seeds	
	The Lost Garden of Heligan Wildflower business film	
	Meadow Match	A novel scheme that matches wildflower seed 'donor' sites and 'recipient' sites in the South West.
Natural capital valuation tools – freely available online tools covering all areas of England	Natural Environment Valuation Online tool (NEVO) Tool	The NEVO Tool is a powerful, open-access, web application designed for regional spatial planning. It can be used to explore the integrated relationships between climate change, land-use change, ecosystem service flows and economic values. SWEEP is helping to improve its accessibility and function – including the ability to upload 'custom area' shape files to explore your own unique areas of land. Contact the team for more information on this. NEVO is endorsed by Defra's ENCA Guidance and one of their 'Featured tools' for assessing natural capital and environmental valuation.
	Outdoor Recreation Valuation (ORVal) Tool	The ORVal Tool is a web-based application that allows users to understand and value the benefits derived from publicly available, accessible greenspace in England, for example, as part of strategic or project appraisal, policy evaluation or natural capital accounting. It also provides contextual information about land cover, land uses, water margins, special designations and points of interest found in or near each recreation site.

		ORVal is endorsed by Defra's ENCA Guidance and one of their 'Featured tools' for assessing natural capital and environmental valuation.
New ways of considering, managing and valuing the marine environment	A Marine Natural Capital Asset and Risk Register. Journal of Ecology paper 2022	Explains the asset and risk register (first of its kind for the marine environment) - how it creates a baseline of current marine natural capital assets and enables better decision making to secure future benefits. Working with 7 councils across the SW, this has been applied to various specific sites eg. Tamar and Exe estuary; Isles of Scilly; Plymouth Marine sound
	North Devon Marine Natural Capital Plan	UK first local Marine Plan based on a natural capital - develops and tests a local spatially evidence base to support discussions for opportunities and risks for activities, developments and management approaches in the marine environment.
	Various other resources supporting marine natural capital policy and practice improvements – best to talk direct to the team, or see https://sweep.ac.uk/projects/marine-natural-capital/	Integrating a marine natural capital approach into sustainability appraisal; marine net gain; sustainable fisheries; sustainable finance.
Improved forecasting of coastal wave and water levels to better protect/ enhance coastal zones and businesses	OWWL – Operational Wave and Water Level model OWWL film	This predicts waves, water levels, and wave overtopping hazard around the southwest coast of the UK. Improving on other forecasts it provides more timely, localised, accurate and high spatial resolution data. It has been applied and used by the EA in the SWest, and in South Wales; bespoke models delivered to benefit local businesses e.g. Offshore Shellfish Ltd and Bombora Energy; 100s of wider coastal stakeholders are signed up to receive the forecast which is enhancing their coastal management decisions.

	Film - Crantock beach hazard forecasting	Developed in collaboration with RNLI, this real-time innovative 'Smart Beach' signage and technology is helping to save lives at the coast.
	Film - North Devon World's first surf reserve	A recent designation which will help boost local business/ support coastal and marine conservation work
	Coastal Change Management Area mapping in North and East Devon	A new, scientifically robust method for demarcating CCMAs – used to mapping the whole of Taw Torridge and Sidmouth coastline enabling better decisions around coastal planning and engineering decisions.
Supporting mariculture development in the South West Evidence and best practice recommendations to support sector development and regulation	Supporting Mariculture Development: Evidence for Informed Regulation	Policy Brief and Policy Statement This project bought together experts from the fields of marine planning, regulation, management, science, and industry to explore opportunities to streamline regulatory processes and clarify evidence requirements for emerging marine aquaculture (mariculture) developments focused on the South-west. A design-workshop explored case studies including marine licensing, aquaculture strategy, mariculture planning in association with fishing, and mariculture developments around MPAs. Findings fed into the English Aquaculture Strategy.
	Potential for marine aquaculture development in and around Marine Protected Areas (MPAs) in England.	Policy Brief and Policy Report Synthesis of evidence and recent developments in marine policy-making and decision support tools for enabling the sustainable development of mariculture sites, species and technologies in and around marine protected areas (MPAs).
South West land use scenario planning (to 2050), effects on water quality	Future land-use scenarios developed to inform modelling of freshwater water quality in Exe Catchment and its impact on growth of the aquaculture sector in South West England	Executive Summary (with hyperlinks to all other resources) Full Report

and impact on potential growth of South West mariculture sector		Descriptions of co-created Future Land Use Scenarios mapped out for the South West to 2050 Visit the SWEEP Aquaculture and Water Quality webpage to access these resources and other key information and tools for assessing the impacts of land use on water quality, and the viability of coastal bivalve aquaculture in the UK and South West England in particular. https://sweep.ac.uk/projects/water-quality-and-aquaculture/
Wholescape evaluation: **impacts of land use and climate change on water quality and bivalve shellfish aquaculture in Exe catchment and estuary.**		**Exe Catchment Investigation** - Wholescape assessment of water quality status, drivers and implications for ecosystem health and services, including shellfish aquaculture. Produced with West Country Rivers Trust. Report & Appendices **Modelling** – Provides the first highly-integrated and innovative modelling and evaluation method for comprehensively evaluating the effects of potential future land use changes on water quality, and their associated impacts on shellfish farming in estuarine and adjoining coastal waters. Innovations notably include modelling the shellfish uptake of pathogens (via ShellSIM) and the valuation of costs and benefits throughout the aquatic system (via the NEV models). Brings to life, for the first time, the UK's National Ecosystem Assessment future land use scenarios in the South West, in relation to their potential effect on water quality in the Exe Catchment and shellfish farming in the Exe Estuary. • Graphical report - 25-page flipbook

		• Slide set – with hyperlinks Visit the SWEEP Aquaculture and Water Quality webpage to access these resources and other key information and tools for assessing the impacts of land use on water quality, and the viability of coastal bivalve aquaculture in the UK and South West England in particular. https://sweep.ac.uk/projects/water-quality-and-aquaculture/
Exploring effect of agricultural (weed killer) run-off during periods of high rain fall on the South West's estuaries	Acid herbicide catchment wash-off scenario exploration tool	The Acid herbicide catchment wash-off scenario exploration tool can be used to explore the potential impacts of acid herbicides on phytoplankton in South West's estuaries. Using a simple logic chain risk assessment process, it has been designed to provide a means for simple, high-level analysis and exploration of the relative risks from acid herbicide wash-off from agricultural land during periods of intense rainfall. The approach is easily adaptable to incorporate new catchments, chemicals and future scenarios. Details of the tool are set out in the guidance report and the spreadsheet tool is available from Dr Ross Brown (Ross.Brown@exeter.ac.uk). An application of the tool to five catchments within South West England (Camel, Clyst, Exe, Kenn, Taw & Torridge) is available on request from Dr Ross Brown (Ross.Brown@exeter.ac.uk).