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Monitoring Sustaining the Gwent Levels for the Sustainable Management Scheme Project

Methodology report

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Report prepared by:
Samuel Pike, FRGS AFRSPSoc CGeog (GIS)
Dr Katie Medcalf CEnv

Environment Systems Ltd
9 Cefn Llan Science Park
Aberystwyth
Ceredigion
SY23 3AH

Tel: +44 (0)1970 626688
www.envsys.co.uk

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Executive Summary

The Sustaining the Gwent Levels Project is a Welsh Government-funded Sustainable Management Scheme on the Gwent Levels. A key objective of this project is to facilitate farmer/land manager engagement with new and developing policies, processes and mechanisms that have the potential to support sustainable land management. It aims to create a positive environment in which the established project partnership of organisations, farmers and landowners, can work together to develop knowledge, skills, and trust, so that challenges are met collaboratively and adaptively both during and beyond the lifetime of this initiative.

A fundamental part of the project is the need to understand the spatial spread of the ecosystem services, and how they, and the effect of the overall management, can be monitored. Environment Systems Ltd has looked at how to design, implement and deliver a programme for examining these spatial trends, and suggest how they can be incorporated into future delivery and monitoring for the Gwent Levels. This required the collection of data across key environmental parameters. Analysis was undertaken to describe the health and resilience of the area’s land-based natural resources (including areas of interface with the freshwater and marine environments) and associated ecosystem services. An emphasis was placed on considering how key species interact with the ecosystem services.

As well as spatial models, a detailed survey of farmers was conducted, split between those who participate in the scheme, and those that do not. This was used to better understand how the scheme is operated from the farmer's perspective, and explore their attitudes and associated behaviour towards it.

This document comprises the methodology statements of the project. It is accompanied by a PowerPoint presentation of the mapping which shows the results. The information in this report can be used for future delivery for Gwent Levels.

For the modelling, seven key contributing themes were identified for spatial analysis:

- Waders (Lapwing habitats)
- Pollinators (Shrill Carder Bee habitats)
- Landscape connectivity (Bat habitats)
- Landscape structure
- Aquatic habitats
- Water
- Carbon

For each theme, four models were produced examining a) the quality of the habitats for the themes, b) their connectivity or risk, c) their opportunity for expansion into the wider landscape, and d) three scenarios based on different intensities of urban and agricultural development.

Each model was developed using the Spatial Evidence for Natural Capital Evaluation (SENCE) rule-based approach. This rule-base is built around how key environmental factors interact in different ways, creating spatial variability. The environmental factors are represented in the spatial input data and can be used to describe how the biophysical characteristics of a parcel of land interact. By understanding these characteristics, it is possible to infer the function/quality that each parcel of land provides. Using water quality as an example, agricultural habitats are scored low and woodlands are scored high; as woodlands minimise soil erosion, reduce sediment, and absorb polluting chemicals, whereas agricultural areas may contribute negatively to those characteristics. Similarly, steep slopes are scored low and flat areas are scored high, as steeps slopes are more likely to contribute to run-off rather than the water be absorbed into flatter ground. Combining these scored characteristics creates a dataset where agricultural areas on slopes are worst for water quality, woodland on slopes / bare ground on flat ground are moderate contributors, and woodlands on flat ground are best for water quality. Experts selected by RSPB Cymru were sought to aid, and check, the rule development for each of the key themes.

The input environmental factors were mostly derived from Earth observation data and associated indices, such as Normalized Difference Vegetation Index (NDVI). These were used as proxies for vegetation biophysical properties such as vegetation improvement, and floristic diversity.

For the quality models, broad habitat data was used as a key factor, with each habitat type scored from low to high, relative to how the key themes responded to that habitat. Scored biophysical property data, such as canopy height, productivity and floristic diversity, were used as modifiers to the habitat.

For the connectivity models, the highest quality areas were selected as 'core' areas. The rest of the dataset was used as the cost data in a cost-distance analysis. If the connectivity of a key theme was a specific species, the core area was extracted from the nesting/roosting quality dataset, and the cost data was from the foraging data. This therefore modelled how well-connected foraging sites were to the best nesting/roosting sites. The risks models for water and carbon followed the same SENCE principles as the quality models, where the environmental variables were scored according to the themes risk; erosion for water, ground disturbance for carbon.

Opportunity models for each key theme were produced independently from one another. Some of the key themes compete for opportunity space in the levels, with the different species and themes requiring different uses of the land. An Interaction Matrix was created to inform decision-makers of the synergies and conflicts of the opportunity datasets.

It is far more cost-effective to continually update a baseline dataset, than to periodically re-map/model the whole area. Considerations for keeping the base data alive is presented through semi-automated habitat monitoring using Earth observation imagery, and differences in spectral signatures of an areas compared to the rest of that habitat type. The prospect of automation, cloud computing, and the benefits of data products over data handling is presented.

Finally, recommendations are suggested for future habitat data acquisitions and modelling, the importance of ground survey data, the use of biophysical data in monitoring, how the data can be presented to key stakeholders, and the concept of scale.

1 Introduction

This collaborative project, between RSPB Cymru and Environment Systems, has looked at how to design and implement a programme for delivering and monitoring the SMS scheme for the Gwent Levels. This required the collection of data across key environmental parameters. Analysis was undertaken to describe the health and resilience of the area's land-based natural resources (including areas of interface with the freshwater and marine environments) and associated ecosystem services. An emphasis was placed on considering how key species interact with the ecosystem services.

This document comprises the methodology statements of the project. It is accompanied by a PowerPoint presentation of the mapping which shows the results. The information in this report can be used for future monitoring of the Gwent levels.

1.1 Context

1.1.1 RSPB

The Royal Society for the Protection of Birds (RSPB) is the largest wildlife conservation NGO in Europe. It has more than 2,000 paid staff, approximately 17,000 active volunteers and over 1.2 million subscribing members. It manages just over 200 nature reserves throughout the UK, covering around 150,000 hectares of land, as well as delivering projects and wider conservation management at the landscape-scale. Other key functions include environmental research, advisory, education, policy and advocacy work.

1.1.2 Environment Systems

Environment Systems is an established environmental and agricultural data company, providing trusted evidence and insight to governments and industry across the world since 2003. Consultancy delivers bespoke advice and solutions for land management, monitoring and policy for ecosystems, natural capital evaluation, agricultural trials and agricultural supply chains. Environment Systems' satellite Data Services deliver always-on, accessible open data insights from satellite Earth observations analytics.

1.1.3 Sustaining the Gwent Levels for the Sustainable Management Scheme Project

The Sustaining the Gwent Levels Project is a Welsh Government-funded Sustainable Management Scheme on the Gwent Levels.

A key objective of this project is to facilitate farmer/land manager engagement with new and developing policies, processes and mechanisms that have the potential to support sustainable land management. It aims to create a positive environment in which the established project partnership of organisations, farmers and landowners, can work together to develop knowledge, skills, and trust, so that challenges are met collaboratively and adaptively both during and beyond the lifetime of this initiative.

A fundamental part of the project is the need to understand the spatial spread of the ecosystem services, how they can inform future delivery, and how it can be monitored.

There is also a Payment for Ecosystem Services (PES) element of the project (a separate report) that engages with local communities, in order to identify novel mechanisms for funding sustainable land management that secures benefits for society. Understanding the provision and distribution of ecosystem services should help to inform this.

1.1.4 Earth observation

Earth Observation (EO) is the 'Earth-facing' discipline of remote sensing. It utilises both airborne and satellite systems that enable the mapping and monitoring of the surface of the Earth. This provides a wealth of knowledge from the national-scale to the field-scale perspective, as well as tracking cause, effect and change not directly possible with field work (particularly considering large areas or places difficult to access on foot). Satellite-based EO has rapidly increased in popularity since 1972 with the launch of the first Landsat satellite. Since then, there have been progressive improvements in the spatial, temporal and spectral capabilities within EO sensors, combined with the necessary expertise and processing techniques.

1.2 The Gwent Levels

The Gwent Levels is a unique landscape in South Wales. Formed of two parts, the Caldicot and Wentloog Levels are two areas of low-lying estuarine alluvial wetland and intertidal mudflats adjoining the north bank of the Severn Estuary, either side of the River Usk. The area covers approximately 57 square kilometres and is a mixture of coastal floodplains, drainage channels known locally as 'reens', saltmarshes and mudflats. It has been estimated that there are over 900 miles of reens, forming 'wet fences' between field parcels and extending deep into current urban areas. This mix of wetlands creates the platform for the distinctive biodiversity that exists in the area. The majority of the area is a Site of Special Scientific Interest (SSSI), with the Newport Wetlands also being a National Nature Reserve (NNR). The tidal parts of the Severn Estuary is of international significance to wetland birds and is designated as a Ramsar site, as well as a Special Area of Conservation (SAC), and Special Protection Area (SPA).

However, the Levels have been, and continue to be, subject to external pressures that impact on this biodiversity. In particular, there has been increasing agricultural improvement, leading to field drainage, ploughing of hay meadows, and arable cropping. The area is also subject to pressures of urban expansion from Newport and Cardiff, and subject to urban fringe pressures such as fly-tipping, and rubbish disposal.

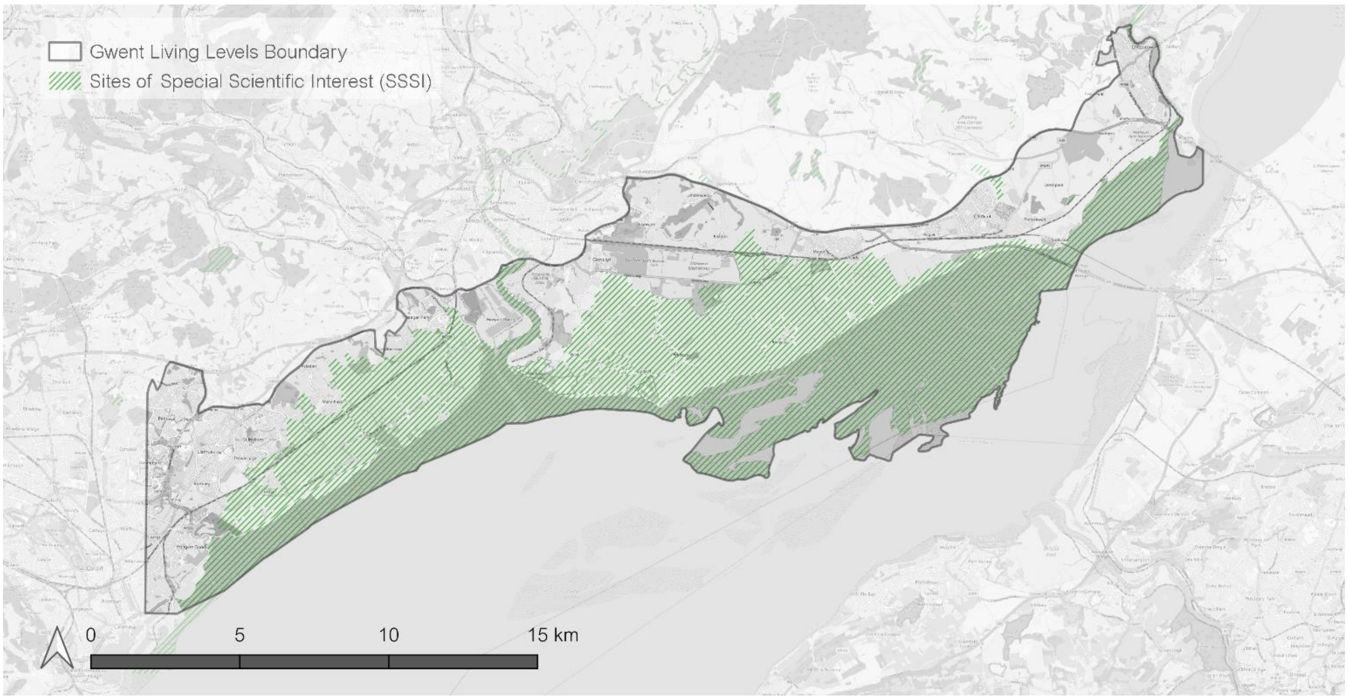

Figure 1-1: Gwent Living Levels are of interest and SSSI boundary

1.3 Rationale

Across the Levels, there is a large amount of monitoring activity already taking place by various bodies for specific species or programmes; for example, SSSI monitoring by NRW. In order to avoid duplication of effort, our monitoring concentrates on key species and features related to ecosystem services that operate at scale. The outputs from this project should be compatible and complementary to existing activity, adding value by filling in gaps.

1.4 Key themes

The following key contributing features to a positive environment in the Levels were investigated:

Waders (Lapwing habitats)	Waders are a flagship presence on the levels, their presence is inherently linked to the extent and quality of wet grassland habitats. Lapwing specifically is a key species, and this monitoring programme considers Lapwing as a representative species.
Pollinators (Shrill Carder Bee habitats)	Pollinators provide a key ecosystem service for food provision and biodiversity. They depend on the quantity, quality, and distance of flowering plants, as well as good grassland condition and connectivity. In the Gwent levels the ditches, reens and their associated back side vegetation provide a key habitat. The Shrill Carder Bee was chosen as the indicator

	species for this aspect, as it is a key species of conservation interest.
Landscape connectivity (Bat habitats)	Landscape connectivity, and the movement of species, are key to retaining biodiversity and functioning natural capital. The suitability of bats of different frequency ranges was modelled, to illustrate how they utilise the landscape, to show how woodland connectivity can be maintained and enhanced, and what effect this should have on maintaining species numbers and genetic resilience.
Landscape structure	Many ecosystem services and key biodiversity features act at the whole landscape-scale. To address this, we considered the structure of the landscape, and its heterogeneity, in terms of the wooded features.
Aquatic habitats	Aquatic habitats are a main feature on the Levels, with ditches and reens used as a mechanism for controlling flooding, and also key features adding to the biodiversity. The quality of these habitats were assessed by considering their condition and connectivity.
Water	The Gwent Levels is a water-based landscape. It is vital to ensuring that the water within the ditches and reens are of a suitable quality for agricultural purposes, and to support biodiversity. Water quality was modelled alongside the risks that the surrounding areas contribute to it.
Carbon	Carbon storage and sequestration is a key service that helps mitigate climate change. The overall carbon budget of the levels was modelled and calculated, and a baseline set against which to record change.

For each of these features we undertook the following actions:

- Modelled the current baseline landscape quality for each feature.
- Modelled the connectivity of landscape features, or, where relevant, model the risk to the service.
- Considered the relevant opportunities to enhance the habitat and species resource through appropriate land management, building on the baseline mapping and modelling.
- Envisaged three scenarios and their impact on the theme qualities, based on the status quo, agricultural intensification, and environmental improvements.

2 Non-technical summary

2.1 Data summary

This project makes use of a significant amount of high-resolution satellite imagery, with different systems observing the Earth in different ways. Sentinel-1 is a radar system, and behaves similar to a bat; a signal is sent out, hits a feature, bounces back, and the signal recorded. The strength of the return indicates the roughness of the feature. Sentinel-2 is an optical system, and behaves like our eyes; light (of different wavelengths) comes from the sun, hits a feature, some of it is absorbed / some reflected back, with the intensity of the reflected light recorded. The recorded reflectance for each light wavelength is different for different features/habitats.

Imagery from these types of sensors can tell us a lot about the biophysical properties of habitats, such as their health, productivity, and species diversity.

Ancillary data was also sourced. This is contextual information that helps with the analysis, classifications, and modelling, such as elevation data, locations of the reen network, and the boundaries of woodland and arable areas. Combining EO and ancillary data allows for more contextual information to be created, such as canopy heights with woodlands, and floristic diversity within fields.

2.2 Modelling summary

2.2.1 Overview

For each theme identified, four models were produced examining:

- the quality of the habitats for the themes
- their connectivity or risk
- their opportunity for expansion into the wider landscape
- three scenarios based on different intensities of urban and agricultural development.

Each model was developed using the Spatial Evidence for Natural Capital Evaluation (SENCE) rule-based approach. This approach is built around how key environmental factors (such as habitat and topography) interact with each other in different ways to grade the importance of any area of land into a simple categorisation of suitability/quality, based on expert and scientific knowledge. By understanding the requirements for the model (e.g., suitable habitats for waders), and understanding what the input data is showing (e.g., habitats, floristic diversity etc) it is possible to infer the function/quality of the land for that model.

Using water quality as an example, agricultural habitats are scored low and woodlands are scored high; as woodlands minimise soil erosion, reduce sediment, and absorb polluting chemicals, whereas agricultural areas may contribute negatively to those characteristics. Similarly, steep slopes are scored low and flat areas are scored high as steeps slopes are more likely to contribute to run-off, whereas water is absorbed into flatter ground. Combining these scored characteristics creates a dataset where agricultural areas on slopes are worst for water quality, woodland on slopes / bare ground on flat ground are moderate contributors, and woodlands on flat ground are best for water quality. This is best described in a matrix, as below in Table 2-1, where the higher the score, the better the environmental factor contribution to improving water quality.

Table 2-1: Representative illustration of model scoring

			Slope		
			Flat	Moderate	Steep
		Score	3	2	1
Habitat	Arable	1	4	3	2
	Grassland	2	5	4	3
	Woodland	3	6	5	4

Experts selected by RSPB Cymru were sought to aid, and check, the rule development for each of the key themes.

2.2.2 Model development

For the quality models, broad habitat data was used as a key factor, with each habitat type scored from low to high, relative to how the key themes responded to that habitat. Biophysical property data such as canopy height, productivity and floristic diversity, were also scored and used as modifiers to the habitat. Two quality models were produced for the species-specific themes — one for nesting/roosting suitability and one for foraging suitability. Both these models were then combined to create an overall quality map for that theme.

For the connectivity models, cost distance analysis was used to identify how easy it is for that theme's vector to move from one area of high quality to another — essentially examining how well-connected good quality areas are. A cost distance model doesn't calculate the physical distance, but rather the total 'effort' (or cost) it takes to get there. To model this, 'core' high quality areas (e.g., good nesting/roosting sites) were identified as the starting locations, and the lower quality areas were the cost to travel. This can be used to represent, for example, a lapwing chick wanting to travel from a nest to a foraging site. Crossing an open patch of wet grassland would have a lower cost than several reens, ditches, hedges and a woodland.

Risk models were required for the water and carbon themes. These were developed following the same SENCE principles as the quality models, where the environmental key factors were scored according to the themes risk; erosion for water, ground disturbance for carbon.

2.2.3 Scenario modelling

The RSPB Cymru had considered three different future scenarios for the Gwent Levels, and what the activities and behaviour of landowners in those scenarios might look like:

- **Status Quo**, illustration of the current development pressures on the Levels projected into the future
- **Intensification**, indicating a future for the Levels if development is increased, and farming intensified more than the status quo scenario
- **High Nature Value**, which looks at increasing management aimed at improving biodiversity conservation, and ecosystem service delivery, across the Levels

For each scenario, the habitat data was manually edited to better represent the descriptions above, and the quality models re-run for each theme. For example, manually reclassifying areas of grassland into anthropological to represent urban expansion. Re-running the quality models with this addition would, for example, reduce the areas of wet grassland, and thus illustrate a loss of suitable habitat for lapwings.

2.3 Monitoring summary

2.3.1 Habitats

It is far more cost-effective to continually update a habitat dataset, than to periodically re-map the whole area. A Living Map is one that evolves through local feedback, field surveys and satellite imagery, and ensures that a habitat map remains up-to-date.

It is recommended to first establish a flag-and-check change-detection system. This approach uses the spectral information within the imagery to identify areas that are different from what is expected. For example, if an area of grassland has a significantly lower reflectance than the rest of the grassland classes, it is likely that the habitat has changed into something else. These areas can be flagged and checked in the field during surveys, from local landowner feedback, visually assessed using up-to-date imagery, or by enthusiastic local residents.

After several years, it is possible to use the areas that haven't changed to form training and validation data in more automated, AI routines. This is the same principle as used for the UKCEH LCM annual updates (UKCEH, 2020), and reduces the field survey effort required - though it is recommended that outputs are still validated on the ground as confirmation.

2.3.2 Models

The concept and methodology of the models were designed specifically for use within a monitoring framework, where new EO imagery can be scored for each model, and the SENCE methodology re-run. The difference between the new and old SENSE outputs would indicate increases, or decreases in habitat quality, connectivity, risk, or opportunity.

Models should be compared on a seasonal like-for-like basis, so models based on summer imagery should not be compared against an output based on a winter imagery. The majority of the EO data is from optical-based systems, which have reduced capabilities during cloud conditions. This can be mitigated by creating composites from multiple images.

Individual EO images can be used to identify significant changes in land cover, such as tree felling or the timings of harvest.

2.3.3 Automation

The majority of the models presented here rely on easily obtainable EO data, and the SENSE methodology can be programmed as automated routines, using the EO data as and when it is required. This would ideally require a library of programming scripts and a cloud-based infrastructure for processing. It is often more time- and cost-effective to acquire data products and services that can be tailored to specific requirements, rather than building and maintaining a system from scratch.

3 Data

3.1 Earth observation imagery

All imagery from Sentinel-1 and Sentinel-2 sensors, captured throughout 2018 and 2019 (Figure 3-1), were acquired through Environment Systems Ltd Data Service (ESDS). These were corrected for their geometry, topographic alignment, radiometry and atmospheric interference, where applicable.

An additional ratio band (VH/VV) was calculated for the Sentinel-1 imagery. Temporal composites of Sentinel-1 were created for each calendar month, year, and growing seasons.

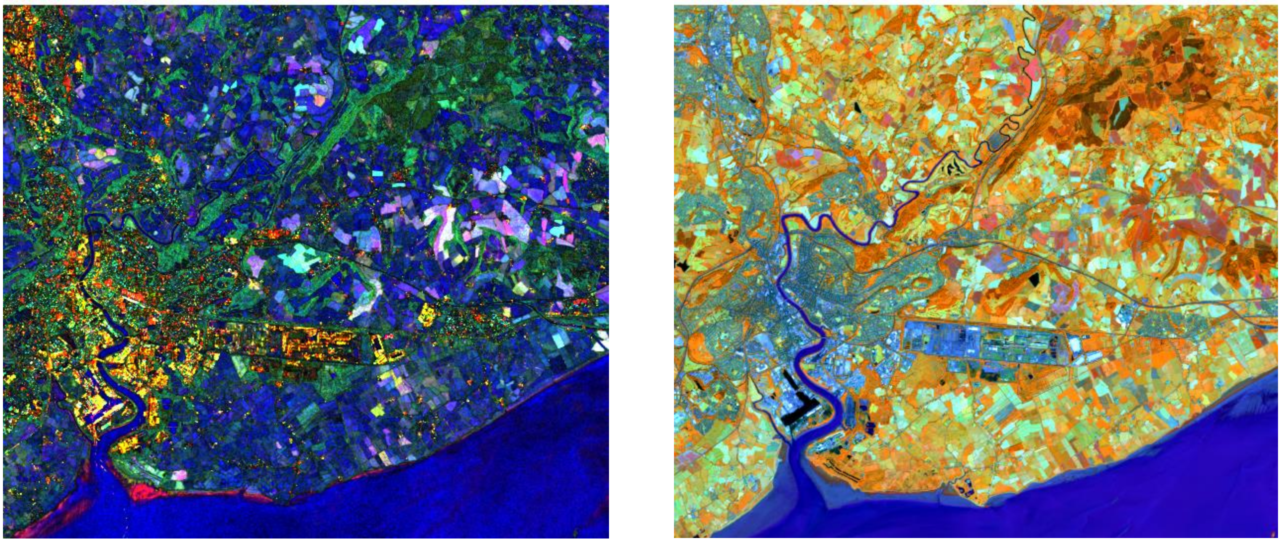

Figure 3-1: Subset of a temporal composite Sentinel-1 (left) and single capture of Sentinel-2 (right)

Sentinel-2 imagery from ESDS is processed to six bands, with cloud masking, with specifications below (Table 3-1):

Table 3-1: Overview of Sentinel-2 ESDS specifications

Sentinel-2 band	Central wavelength, nanometres (nm)	Bandwidth, nanometres (nm)	Resolution, metres (m)
Band 2 – Blue	492.4/492.1	66	10
Band 3 – Green	559.8/559.0	36	10
Band 4 – Red	664.6/664.9	31	10
Band 5 – Red-edge	704.1/703.8	15/16	20
Band 8 – NIR	832.8/832.9	106	10
Band 11 – SWIR	1613.7/1610.4	91/91	20

Three indices were produced for each data capture:

- Normalised Difference Vegetation Index (NDVI)
- Normalised Difference Moisture Index (NDWI)
- Enhanced Vegetation Index (EVI)
- Normalised Difference Red-edge Index 3(NDRE3)

Temporal composites of Sentinel-2 data and indices were created for each calendar year, month, and growing seasons.

3.2 Ancillary data

Ancillary data combines information on location, attribute information (characteristics of an object, event or phenomena) and temporal information. There is a wealth of existing information relating to the natural environment, and land management. By combining these data with satellite imagery within a Geographic Information System (GIS), it is possible to extract meaningful, spectral information, and to mask areas out from analysis.

The geospatial data acquired for this project include:

- OpenStreetMap
- National Forest Inventory (NFI)
- OSOpenData
- Ancient Woodland Inventory
- Water Framework Directive
- Natural Resources Wales (NRW) Protected Areas Designations
- NRW 2 m lidar Digital Terrain Model (DTM)composite
- NRW 2 m lidar Digital Surface Model (DTM)composite
- Met Office HadUK-Grid annual precipitation

3.3 Derived data

Additional data for modelling were derived from both the satellite imagery, and the ancillary data. A list of these, their sources, and brief description are below in Table 3-2.

Table 3-2: Derived data and their sources

Derived data	Source(s)	Description
Habitat	Various	Object-based, semi-automatic classification with manual adjustments
Lidar canopy height model (CHM)	NRW 2 m lidar DTM; NRW 2 m lidar DTM	Difference between DSM and DTM
Hedge width	Habitat; lidar	Width of areas with CHM values greater than 2m, outside of woodland and urban habitats
DTM slope	NRW 2 m lidar DTM	Slope, in degrees of the topography
Distance from habitats	Habitat	Distance, in metres from specific habitats, such as hedges
CHM heterogeneity	Habitat; CHM	Standard deviation of CHM values, within habitat polygons
Floristic diversity	Sentinel-2	Standard deviation of near-infrared values, within habitat polygons
Agricultural intensity	Sentinel-1	Standard deviation of radar backscatter values across the growing season
Water pooling potential	NRW 2 m lidar DTM	Difference between the raw, and a filled DTM
Coastal flooding	NRW 2 m lidar DTM	Elevation of water originating from the coast, in meters, required for that area to be flooded
Till month	Sentinel-1; Habitat	Month of the year that recorded the greatest loss in biomass

3.4 Field surveys

Field survey work was due to commence throughout 2020. However, due to SARS-CoV-2, the majority of this effort was pushed back to 2021.

3.4.1 Lapwing

Survey areas were identified using existing survey data and satellite imagery to identify a suitable range of nesting sites.

Lapwing survey data from RSPB Cymru was examined for observation densities during the months of March - June, throughout the survey years (1984 - 2002). The areas that had the greatest densities were manually delineated for site visits (Figure 3-2), to take place every three weeks for five visits, following the Bolton et al. (2011) methodology. Fields within these areas were visited individually, and the number of lapwings and their growth stage are recorded, which were used to approximate the population size and annual breeding success.

3.4.2 Shrill Carder Bee

The sampling strategy for Shrill Carder Bee (SCB) required the landscape habitat to be split into two broad habitats; improved grassland and 'structurally and species diverse' grassland. The latter included semi-improved grassland, unimproved grassland, marshy grassland, hedges, paths, and the vegetation along the reens and ditches.

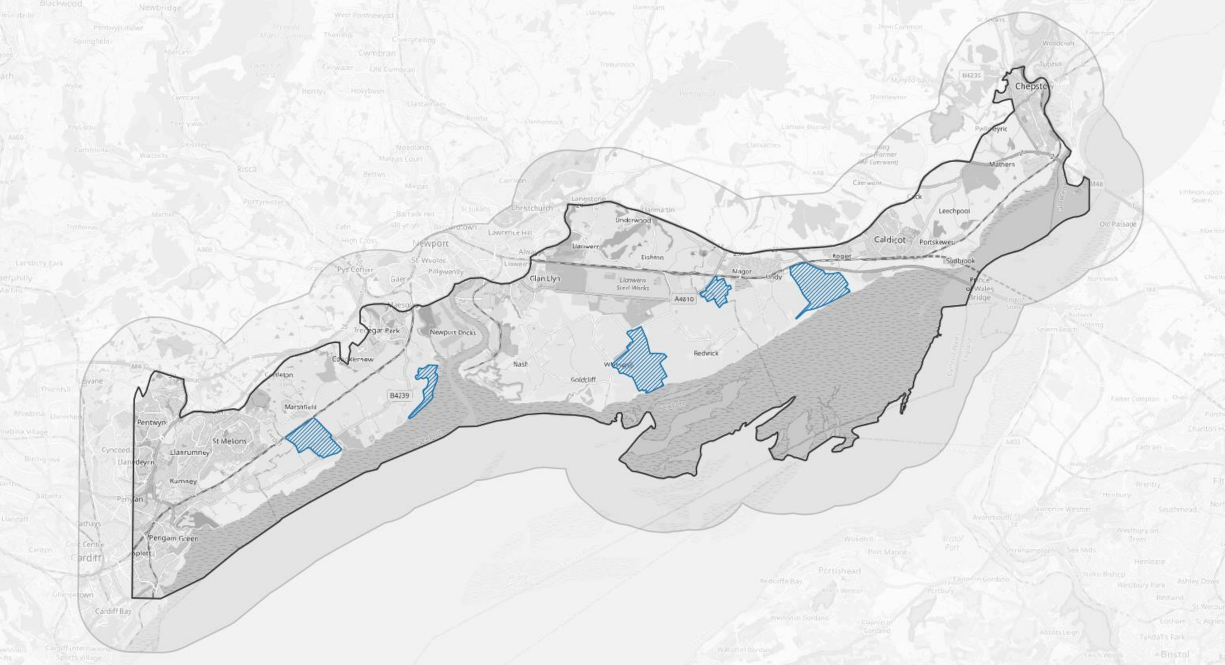

Figure 3-2: Area extents of Lapwing survey locations

Previous SCB fieldwork, conducted by the then Countryside Council for Wales (CCW) throughout 2009, allowed for the identification of habitats in close proximity to known SCB territory. An equal number of sites (Figure 3-3) were randomly selected based on the broad survey habitat category and whether or not there is previous evidence of SCB activity.

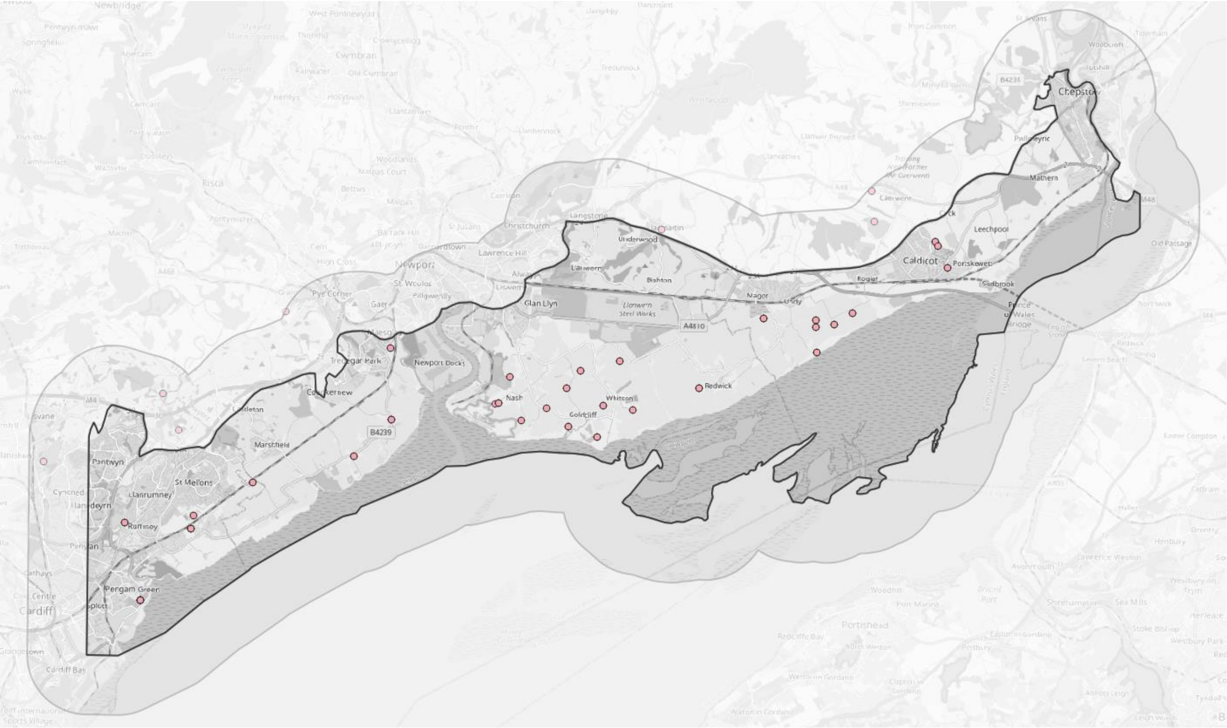

Figure 3-3: Location of field visit for Shrill Carder Bee habitat survey

Field survey work took place between 28th July and 2nd August 2020, and included the following attributes (Table 3-3):

Table 3-3: Shrill Carder Bee habitat survey attributes

Field	**Description**
Date	Date of survey
Broad habitat type	Broad habitat type
Condition of field	Subjective, and relative description of grassland type condition. E.g., Fair, ground very compacted.
Boundary type	E.g., Hedgerow, Hedgerow with trees, Ditch
Scrub cover and location	Percentage cover of scrub habitat
Management of habitat	Information on land use, e.g., cattle
Reens present	The presence of reen
Condition of reen	E.g., Percentage cover of shading,
Species list	Dominant vegetation present
Shrill carder bee sighting	Confirmation of SCB present

3.4.3 Bat presence

To allow valid comparisons to be made between bat activities, eight calibrated automated detectors (Anabat Swift Bat Detector) were set-up to record simultaneously throughout July – September 2021. The method of using detectors simultaneously, allowed for a quantitative assessment of the reliance of certain species on various linear features which could then be fed into reen/hedgerow management practices.

The selection of detector locations were distributed according to a system of stratified sampling, based on the availability of different habitats, topographical features, and landowner permissions. Survey locations included open reens, reens with hedgerows, and hedgerows, within different proximities to broadleaf woodland (Table 3-4). This provided an indication of how bats used these features in the Levels.

Table 3-4: Bat detector location parameters

Proximity to woodland	**Detect. 1**	**Detect. 2**	**Detect. 3**	**Detect. 4**
<= 150 metres	Reen	Reen with one hedgerow	Reen with two hedgerows	Open area
> 150 metres	Reen	Reen with one hedgerow	Reen with two hedgerows	Open area

The physical location of the detectors are provided below in Figure 3-4

Figure 3-4: Location of bat detectors

4 Modelling overview

The project employs the Spatial Evidence for Natural Capital Evaluation (SENCE) (Environment Systems, 2021) approach to suitability mapping, developed by Environment Systems. SENCE mapping displays the suitability of each area of land for each factor under consideration.

The SENCE approach aims to identify and use the most suitable data for analysis. It can utilise both directly measured, and modelled data. The methodology assesses possible data limitations during a data audit process, ensuring that data are used appropriately.

SENCE takes a pragmatic approach to mapping and modelling of land suitability; it is possible, using existing data, to grade the importance of any area of land into a simple categorisation of suitable, limited suitability and unsuitable, based on scientific literature, expert knowledge and development of a scientific rule base. The maps can be used to inform decisions at national, regional and local levels.

The scientific rule base assessment is based on consideration of key factors which interact together in different ways for individual areas of land for each factor under consideration. The key factors determining suitability/quality are:

- habitat and land cover classification (e.g., grassland, woodland, etc.)
- hydrology and climatic conditions
- soil and geology
- elevation and slope

The SENCE process in this project required the completion of successive tasks in order to prepare the service outputs:

- Stakeholder engagement (RSPB Cymru)
- Data collation and creation
- Data suitability assessment
- Rule-base development
- Further stakeholder engagement (RSPB Cymru)
- Refinement of rule-base (with external subject matter experts)
- Modelling and iterations

The maps are a modelled approximation of the situation at the current time mapping took place, based on the data available. Therefore, any proposed local action must be assessed at a site level to validate the mapping, and check the appropriateness of the proposed action. If individual site surveys are undertaken, the results can be fed back into the model layers to help enhance the spatial, and temporal, accuracy of the maps.

4.1 Rule-base development

SENCE uses a rule-based approach to combine individual environmental datasets of relevance to the model in question. This provides a stepped approach to representing the complex ecosystem interactions. Depending on the nature of the ecosystem processes involved (some processes are better-understood than others, and some lend themselves to modelling better than others) and the nature of the available data, it may be possible to represent the whole of the system/interaction, or it may only be possible to represent it in part.

The rule-base is built around how key environmental factors interact in different ways, creating spatial variability. The key factors are represented in the spatial input data and can be used to describe how the biophysical characteristics of a parcel of land can be applied. By understanding these characteristics, it is possible to infer the function/quality that each parcel of land provides, and therefore identify the suitability (Figure 4-1). For example, soil identified in data as silty could be scored as highly susceptible to erosion, but combined with data that shows it lies on flat ground and under broadleaved woodland, the output model may not show that area at particularly high risk.

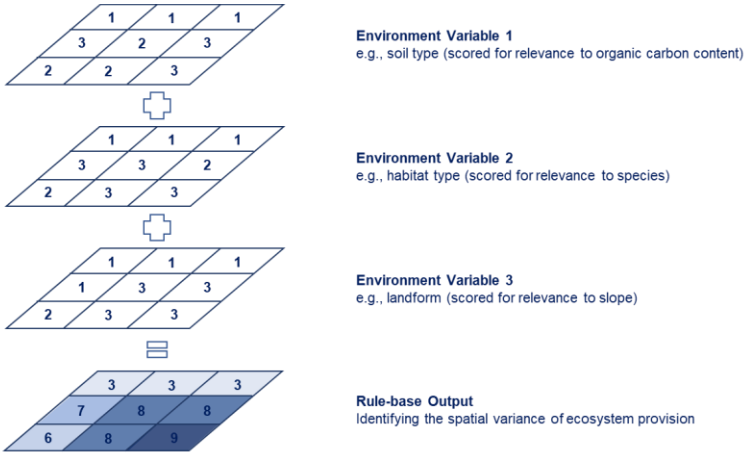

Figure 4-1: Representation of the underlying principle behind the SENCE methodology

4.2 Biophysical properties

A current land cover map is essential for ecosystem service modelling. A landscape-scale habitat dataset is required to identify the broad land cover vegetation types. This was achieved using all the available data acquired for the project, and a remote sensing supervised rulebase classification. The output habitat map was checked by RSPB Cymru staff for errors and omissions.

The identified habitat classes were kept broad (e.g., grassland) rather than relatively detailed (e.g., improved grassland) as there was no fieldwork available at the time (due to SARS-CoV-2) to train the classification, or validate the distinction between the class separations (e.g., improved vs. semi-improved grassland).

Incorporating the use of remote sensing data with the habitat data allowed us to consider the biophysical properties of the vegetation in terms of ecosystem services. This allowed us to evaluate how productive and heterogeneous the grassland is within the overall grassland class, adding sensitivity to the broad-scale analysis.

A biophysical approach to the modelling also benefits the monitoring of the key features. The properties are derived from several, individual EO datasets and indices, all of which can be easily replicated and integrated into the modelling, rather than recreating or updating a detailed habitat map.

4.3 Key themes and models

As described in 1.4, seven themes and proxies were identified as representative priorities of the Gwent Levels. For each theme, four models were identified based on whether the theme was species/habitat-led, or characterising the landscape.

An outline of the themes and models are presented below (Table 4-1).

Table 4-1: Table of themes and models mapped

Theme	**Model**
Waders (Lapwing)	Quality
	Connectivity
	Opportunity
	Scenarios
Pollinators (Shrill Carder Bee))	Quality
	Connectivity
	Opportunity
	Scenarios
Landscape connectivity (Bats)	Quality
	Connectivity
	Opportunity
	Scenarios
Landscape structure	Quality
	Connectivity
	Opportunity
	Scenarios
Aquatic habitats	Quality
	Connectivity
	Opportunity
	Scenarios
Water	Quality
	Risks
	Opportunity
	Scenarios
Carbon	Quality
	Risks
	Opportunity
	Scenarios

Each model type mostly follows the same broad methodology, regardless of theme, briefly outlined in the sections below.

For species-specific quality modelling, two outputs are created; one for nesting/roosting areas, and one for foraging areas. For landscape connectivity (Bats), three different sub-themes were modelled, each representing a different echolocation range and species (Table 4-2). Each range type responds to a variety of landscape features in various ways, with short-ranged species associated more with edge-habitat such as hedgerows and woodland edge. Long-range species tend to be less associated with specific habitat features, utilising open space more frequently than other species, with medium-range species exploiting both habitats to a degree.

Table 4-2: Species of bats modelled for the landscape connectivity theme

Range descriptor	Bat species
Short	Lesser horseshoe
Medium	Pipistrelles
Long	Noctule

4.3.1 Quality

The species/habitat quality models used a rule-based approach to combine individual biophysical datasets of relevance to the species/habitat type in question. The core dataset was the land cover habitat map. The broad classes were scored from low to high based on how suitable they are for the theme. Other relevant EO-derived datasets, geospatial data, and suitable proxies were created specific to the theme, such as NDVI as a proxy for grassland productivity. These were also scored from low to high, and used as the modifiers to the base habitat data.

Compositing these scored datasets together provides an overall, relative, suitability dataset. The scores and outputs can be communicated easily with identified experts of the theme. If there were any amendments required to the input data or scores, these could be adjusted, and the models iterated through.

For the species-specific themes, two quality models were produced, one for nesting/roosting suitability, one for foraging suitability. Both these models were then composited to create an overall quality map.

The biophysical properties, along with their rule-base classes are listed in Appendix A: Biophysical factors used to assess quality model.

4.3.1.1 Considerations for Aquatic quality

For the aquatic habitat theme, it was not possible to assess the reens and water bodies as individual features. This was due to the differences in scale between the features of interest and the satellite imagery, so that the width of a reen would only occupy half a pixel of satellite imagery. A lot of the reens are also highly vegetated, with relatively dense canopies of hedgerows and trees, which would block the 'birds-eye-view' of the satellite data.

It was therefore necessary to consider the habitats, biophysical properties, and factors from the surrounding areas instead, that might influence the quality of the aquatic environment. This was achieved by first applying the SENCE methodology to the required datasets, then buffering the water bodies out into the surrounding landscape and extracting the relevant information through zonal statistics.

4.3.2 Connectivity

Nature recovery networks, or ecological networks, describe how well individual habitats are connected throughout the landscape. This study differs in its approach, as it aims to describe how well-connected good quality areas are throughout the landscape, not just focused on the habitat.

Quality connectivity was modelled using a cost-distance approach. For this method, the highest quality areas from 4.3.1 were regarded as core (sometimes referred to as ‘home habitats'). For species-specific connectivity modelling, the core was only extracted from the nesting/roosting quality outputs.

The quality outputs were also the movement cost - a value expressing how difficult it is for vectors (in this case, the specific species) associated with the theme to move through the landscape. For species-specific connectivity modelling, the movement cost is only associated with the foraging quality outputs.

Core areas have a movement cost of 0 – the species are at home in these most suitable patches. The cost of movement across an area increases, the less suitable the area is. For example, with aquatic habitats, the highest quality areas are considered core, with non-core areas considered as a cost, as this shows how well-connected high quality aquatic areas are. For species-specific themes such as waders (lapwing), the highest quality areas for nesting/roosting are considered core and the foraging quality output is used as the cost, illustrating how well-connected high-quality nesting/roosting areas are to high quality foraging areas.

4.3.3 Risk

4.3.3.1 Risk to water

Land-based erosion during heavy rainfall is a great risk to water quality, as it can often carry pollutants such as sediments, nutrients, organic chemicals, and heavy metals into waterways. It is important to identify locations at particulate risk from erosion, as these areas are likely sources for particular matter and other pollutants entering the water system from run-off. Management intervention in these areas has the potential to simultaneously improve the quality of the land and reduce the amount of diffuse pollution downstream.

Sensitive Catchment Integrated Modelling and Analysis Platform (SCIMAP) uses readily available data (topography, precipitation, and erodibility (based on habitat)) to generate erosion risk following hydrographical principles (Reaney et al, 2016). The low number of required input datasets is one of the main advantages this tool offers, as many hydrographical modelling tools can present problems at the stage of data collation. The output model highlights the relative degree of erosion risk throughout the Levels.

The input erodibility data was modelled from the broad habitat map and EO-derived datasets, and combined together following the SENCE approach. The data and scores used for the erodibility input are outlined in Appendix B: Biophysical factors used to assess risk models.

4.3.3.2 Risk to carbon

There are a number of factors in maintaining long-term carbon stores, such as land cover, land use, and soil carbon concentration. These risks can result in reduced rates of sequestration and the release of stored carbon back to the atmosphere (Galik and Jackson, 2009).

The method to model the risks to carbon storage followed the same principles as the carbon storage quality model. The difference here, is the input data were instead scored for the risks of carbon being released back into the atmosphere and then combined using the SENCE approach, rather than being scored on the potential the data has on storing carbon. For example, arable areas are now scored very high as tilling the land can release the carbon stored in the soil, but broadleaf woodland is scored low, as these habitats are unlikely to be disturbed for many years.

The data and scores used for the carbon risk model are outlined in Appendix B: Biophysical factors used to assess risk models.

4.3.4 Opportunity

4.3.4.1 Waders

Wader opportunity mapping was carried out using a constraints-based approach, i.e. the whole area was initially considered as opportunity space from which unsuitable sites were subtracted. Factors considered as constraints were:

- Best and most versatile land; this land is of high economic value and contributes to food security, it is likely to be needed for more intensive agricultural production.

- Based on mapping carried out previously for this project, those areas already deemed most suitable for waders within the Gwent Levels were excluded
- Some habitat types unsuitable for conversion to wader habitat were excluded (e.g., built-up areas, woodland, etc.).
- Areas with a slope of over five degrees were excluded, as these sites are not suitable for wetland creation.
- Sites within 30 m of perching posts, such as electricity pylons, were excluded as predation from raptors and corvids would be a severe risk. Sites within 100 m of perching posts were considered of lower suitability.
- To account for the danger foxes pose to waders, prime fox habitat was identified by utilising the core patches of the woodland network, a habitat most likely to contain burrows. Areas within 1 km of these sites were excluded from the opportunity space, with suitability increasing with every extra kilometre distant from prime fox habitat.

4.3.4.2 Pollinators

To establish opportunities for the Shrill Carder Bee, all existing habitats were scored with regards to whether it is possible, potentially possible, or not possible and desirable to convert the habitat to a core/home habitat for the species. The resulting opportunities were classed based on their spatial relationship to the existing ecological network. The network was calculated based on cost-distance modelling, and opportunities classed as being either next to existing core habitat, next to existing stepping stones, within the existing network extent, or in the wider landscape. In line with the paradigm of “Bigger, Better, More Joined up” for ecological networks, opportunities to increase the patch size are preferable, followed by opportunities within the existing networks that strengthen the connection between existing habitat patches. Opportunities in the wider landscape can be less efficient to realise, as they cannot rely on species and seed dispersal from existing sites to the same extent as the other opportunity types.

4.3.4.3 Bats

To establish opportunities for bats, all existing habitats were scored with regards to whether it is possible, potentially possible, or not possible and desirable to convert the habitat to a core/home habitat for bat species. To reflect different habitat preferences, this calculation was performed three times, separately for short-, medium-, and long-range species. The resulting opportunities were classed based on their spatial relationship to the existing pollinator ecological network. The network was calculated based on cost-distance modelling. As bat species do not require large patches of habitat for roosting, the best opportunities are those that enhance the landscape permeability by adding foraging sites.

4.3.4.4 Aquatic habitats

To establish opportunities for aquatic habitats, reens were identified that are currently overgrown with hedges. The hedges that are only somewhat overgrown form good opportunities to create functioning aquatic habitats. The most overgrown reens, on the other hand, will be more challenging to convert.

4.3.4.5 Landscape structure

In the Gwent Levels, wetlands and grasslands are of primary conservation concern, with woodlands being secondary landscape features. Woodlands can pose a risk to waders in wetland areas, as they can house fox populations and provide perching spots for birds of prey. The model outlines ways in which the open landscape character of the Gwent Levels can be reinstated through woodland removal, without reducing the overall extent of the network. To do so, stepping stones outside of the existing woodland network were identified, as where those located between multiple, well-connected woodland sites.

If the woodland network is to be strengthened, the most effective sites would be those opportunities within the existing woodland network, but that are located in between disjointed separate patches, and do not over-shadow the reens.

4.3.4.6 Water quality

Scimap (Durham University, 2016) was used to model the location of channels (e.g., sites that flow with water after heavy rainfall), sites that are particularly well connected to the surface water network, and sites at particular erosion risk.

The existing habitats were assessed for their suitability for restoration/conversion into a state more suitable to filter water and prevent erosion, respectively. Sites with potential to contribute more to water filtration were highlighted as opportunities where they are either within 50 m of surface water bodies, within 30 m of channels, or in a particularly well-connected area. Sites with the potential for higher erosion prevention properties were retained if they are located in areas with high erosion risk.

Both opportunity types were combined into one opportunity layer for enhanced water quality.

4.3.4.7 Carbon

To enhance carbon storage in the Gwent Levels, three distinct opportunity types were considered:

- Conversion of arable land
- Rewetting of land
- Tree planting

Tree planting sites where selected from the opportunity layer for the Landscape Structure theme, which highlights the planting that would generate the highest connectivity increase for the woodland network.

Rewetting opportunities were identified by selecting particularly flat (<3° slope), highly productive grassland sites that are within 50 m of existing surface water or reens. Where these have a high maximum carbon storage potential, they are great opportunities for enhanced carbon storage through rewetting schemes.

Conversion of arable land into a semi-natural state will enhance carbon storage at these sites; although most land will be farmed there are ways of increasing carbon by regenerative agricultural techniques, therefore all arable was included in this analysis. Areas were selected if they are currently used as arable land and have a high maximum carbon storage potential.

4.3.4.8 Interactions

There are many competing habitat opportunities in the levels, with the different species and themes requiring different uses of the land.

An Interaction Matrix has been created to inform decision makers on the synergies and conflicts of the opportunity datasets. This matrix lists the key components of the opportunity layers against one another, and scores their potential impact. For example, realising the opportunity to enhance habitats for short-ranged bat species has a strong negative impact on the opportunity to enhance wader habitats, but a strong positive impact on the opportunity to enhance pollinator habitats. This means that the land-owner must make a choice between waders, or bats and pollinators - providing for all three is not feasible.

The interaction matrix is outlined in Appendix C: Opportunity Interaction Matrix.

4.3.5 Scenarios

The RSPB Cymru had considered three different future scenarios for the Gwent Levels, and what the activities and behaviour of landowners in those scenarios might look like:

- **Status Quo**, illustrating the current development pressures on the Levels projected into the future
- **Intensification**, indicating a future for the Levels if development is increased, and farming intensified more than the status quo scenario
- **High Nature Value**, which looks at increasing management aimed at improving biodiversity conservation, and ecosystem service delivery, across the Levels

For each scenario, the base habitat data was manually manipulated to account for the descriptions in each scenario, and the quality models re-run for each theme. For example, in 'High Nature Value', buffer zones are to be maintained alongside water courses and managed as part of a diverse seed-rich /flower-rich habitat. This required the addition of 10 m buffer zones adjacent to rivers and reens. These buffer zones would be scored as such for each theme, and the biophysical properties manipulated to replicate a habitat with low productivity and high species heterogeneity.

The next sections outline the amendments made for each for each scenario. The scenario descriptions are available in Appendix D: Scenario descriptions and adjustments.

4.3.5.1 Status Quo

- Relatively flat areas of grassland and arable fields, outside the SSSI but adjacent to existing large parcels of urban, were reclassed as the latter to represent urban expansion.
- Proposed plans for solar farms were also realised as anthropological development.
- Randomly selected ditches and reens were classed as hedges, to represent neglect of care
- Floristic diversity values were slightly downgraded
- A few small roads were selected, expanded into the wider landscape, and reclassed as anthropological to represent increased fly tipping

4.3.5.2 Intensification

- Further areas of grassland and arable fields were reclassed as urban, with some areas inside the SSSI.
- More ditches were reclassed as hedgerows
- Grassland productivity was further increased, and floristic diversity further reduced
- Large areas of grassland were converted into arable rotations

4.3.5.3 High nature value

- NDVI values were manipulated to provide lower productivity levels, representing reduced fertiliser application.
- The floristic diversity levels were increased to represent more grassland types
- Woodland was created where the opportunity datasets provided it
- Reens were buffered by 10 m. If the buffered areas expanded into arable or grassland, the NDVI and NIRstddev (the standard deviation of NIR) values were adjusted to represent buffer strips
- Some areas of good quality arable were converted to represent wet grassland, scrub, and woodland, as directed by the Carbon opportunity layer

5 Interviews with participating and non-participating farmers

In tandem with the modelling, a detailed survey of selected farmers was conducted in order to understand the views and thoughts of those farmers from their perspective, in terms of how the scheme has operated, their own understanding of what it is meant to achieve and if this is feasible. The selected farmers were split between those who are participating in the scheme, and those not participating.

All questionnaires were developed in consultation with RSPB Cymru and the Project Steering group. Pilot interviews were conducted to test the clarity of questions and the structure of the survey. The participant's and non-participant's attitudes and associated behaviour towards the RSPB Cymru scheme were explored, through a range of structured and semantic differential-type questions. Devised open questions assessed the experiences and perceptions of the scheme, associated communication materials, and the advice received when preparing an application, or considering whether to apply.

Participant issues included:

- Access to and understanding of information regarding the scheme
- Process of developing and submitting application
- Receipt of advice from RSPB Cymru and other sources
- Reasons behind participating
- Reasons for selected activities
- Links with any previous or existing AES agreement
- Current management of areas now not under AES management
- Perceived impact on farming system (farm size and type, ownership)
- Links to initiatives feeding into the scheme
- Counterfactual – what would be done in absence of the scheme
- Overall experiences of the scheme and suggested changes.

The non-participant questionnaire included:

- Expressed reasons for not applying, linked to previous AES experience
- Training and advice received through farm business and for environmental aspects
- Experiences and knowledge of the scheme in terms of purpose and options (prescriptions and payment rates)
- The impact of not applying on farming system
- Links to initiatives related to the scheme
- Future intentions regarding RSPB Cymru, and what would make the scheme more attractive
- Overall attitudes towards AES schemes and the environment

The output from this was a report on the farmer survey and key aspects to connect with the areas of the evaluation. Where possible, it is encouraged that the outputs of this review are fed back to the farmers — possible through a workshop to ground-truth the findings and encourage a dialogue between the different partners.

6 Monitoring Sustaining the Gwent Levels

The data and models presented in this study are predominantly based on high resolution satellite imagery, from Sentinel-1 (radar) and Sentimel-2 sensors (optical). Sentinel data are cost-effective, science-grade, and can be easily integrated into automated routines that can be analysed at scale, when required. The 10 m spatial resolution, high frequency capture rate, and continuity missions make them ideal for the base, and subsequent, data for monitoring systems.

6.1 Monitoring for baseline habitat change

It is far more cost-effective to continually update a baseline habitat dataset, than to periodically re-map the whole area (Medcalf et al., 2015). A Living Map, one that evolves through local feedback, field surveys and satellite imagery, allows for up-to-date information on the spatial extent and configuration of habitats across the landscape to be used for evidence and policy whenever required.

For the continued update of the habitat map, it is recommended to first establish a statistical-based flag-and-check change-detection approach. This method reduces the possibility of creating false-change through errors in subsequent classifications. For example, one classification could classify an area as scrub, and the next could misclassify the same area as hedge. The area would be identified as having changed, but it was an error in the second classification.

Instead, a flag-and-check approach uses the spectral information within the imagery to flag those areas that are statistically spectrally different from what is expected from within each habitat class. For example, generally, grassland habitats have a higher NIR signal than scrub/woodland. If an area of grassland has a significantly lower NIR than the rest of the grassland classes, it is likely that the habitat has changed into something with more scrub/woodland features.

These flagged areas can be checked in the field during surveys, from local landowner feedback, visually assessed using up-to-date imagery, or by enthusiastic local residents. The correct habitat is then attributed into the Living Map (Medcalf et al., 2015).

6.1.1 Classification-to-image Living Map

The average spectral values from the satellite imagery, computed for Principal Components Analysis (PCA), should be extracted from each singlepart habitat polygon. From these figures, the mean spectral values of each individual polygon are compared to the overall mean spectral characteristics of the habitat class it represents. If an individual polygon’s mean spectral value is greater than two standard deviations (Lillesand, Kiefer, and Chipman 2014) away from the mean for the class as a whole, then those individual polygons are considered statistically spectrally different from what is expected for that habitat.

A graphical example of this is provided in Figure 6-1, where those polygons with spectral values in the extremes of the histogram (the areas greyed-out), indicate areas that do not spectrally conform to the habitat as a whole, and could therefore indicate a different habitat/habitat change. Those polygons that are identified as statistically different would be flagged for further investigation.

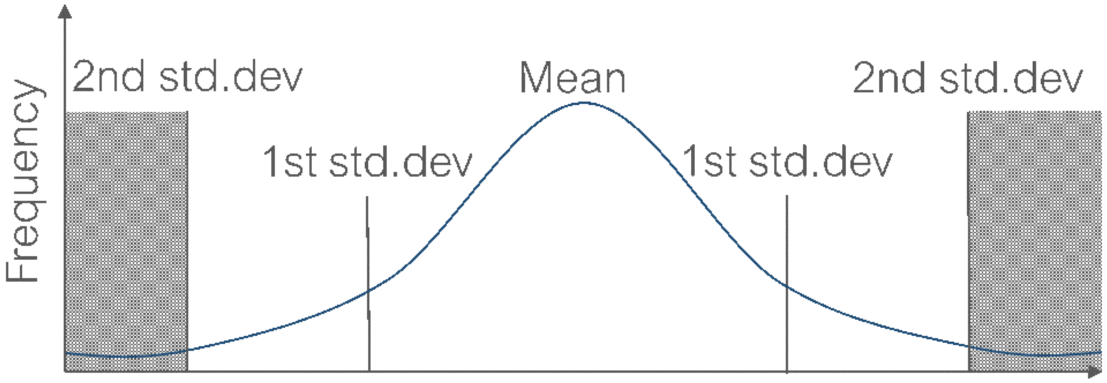

Figure 6-1: Standard deviation of satellite imagery spectral values

The process of maintaining a flag-and-check Living Map could be as follows:

1. Obtain imagery and apply statistical techniques introduced here to identify areas that are likely to have changed
2. Decide on method of check, e.g., through field surveys
3. Add data from field surveys completed throughout the year, or from those that have been carried out from other projects.
4. Final QA of all suggested updates by ecologist
5. Issue the next version of the map.

Additional considerations for using remote sensing data in keeping a habitat map alive are shown in Appendix E: Further Considerations for a Living Map.

6.1.2 Random forest Living Map

Following several (preferably three or more) iterations of classification-to-image change detection updating, it is possible to identify areas that have consistently remained the same habitat type, through each iteration. These consistent, stable areas could form the basis of training and validating a random forest classification. This is the same principle as used for the UKCEH LCM annual updates (UKCEH, 2020), and reduces the field survey effort required - though it is recommended that outputs are still validated on the ground as confirmation. Each iteration should be added to the database of potentially stable habitats, so a 2029 Living Map will be trained using areas that have not changed since the baseline year.

6.2 The value of automation

The concept and methodology of the Quality datasets were designed specifically for use within a monitoring framework. The majority of the datasets rely on easily obtainable, Earth observation-based indices and Analysis-Ready Data (ARD), such as NDVI.

When acquired, the ARDs can be suitably processed, scored according to the theme, replace the baseline data, and the SENSE models re-run. The difference between the new and old SENSE outputs would indicate either an increase, or decrease in habitat quality for that theme. Figure 6-2 illustrates a possible flowchart for monitoring a quality theme.

In the flowchart example, an existing database of key factors and stable biophysical properties, such as topography, are held centrally. Geographical data held externally are extracted from source, such as habitat data. This would ensure that the data retrieved would be the most up-to-date version available. Required Analysis Ready Data (ARD), such as NDVI is extracted and, if required, the spatial variation calculated per field parcel - the boundaries of which can be derived from various sources such as the habitat data. Any new data extracted is scored according to maintained look-up tables, and combined with the existing, scored, key factor data.

It is recommended that datasets are compared in a like-for-like fashion, specifically with regard to image timings. A SENCE output modelled using NDVI captured in summer should not be compared against an output based on a winter NDVI data. It is preferable to ensure the data compared is captured as close to the same time of year as possible (e.g., summer vs summer).

It is important to consider that the majority of the ARDs are from optical-based systems, which have reduced capabilities during cloud conditions. It is recommended to consider temporal, seasonal composites (e.g., summer), rather than individual captures, to reduce the impact of cloud cover and gain suitable coverage of the area.

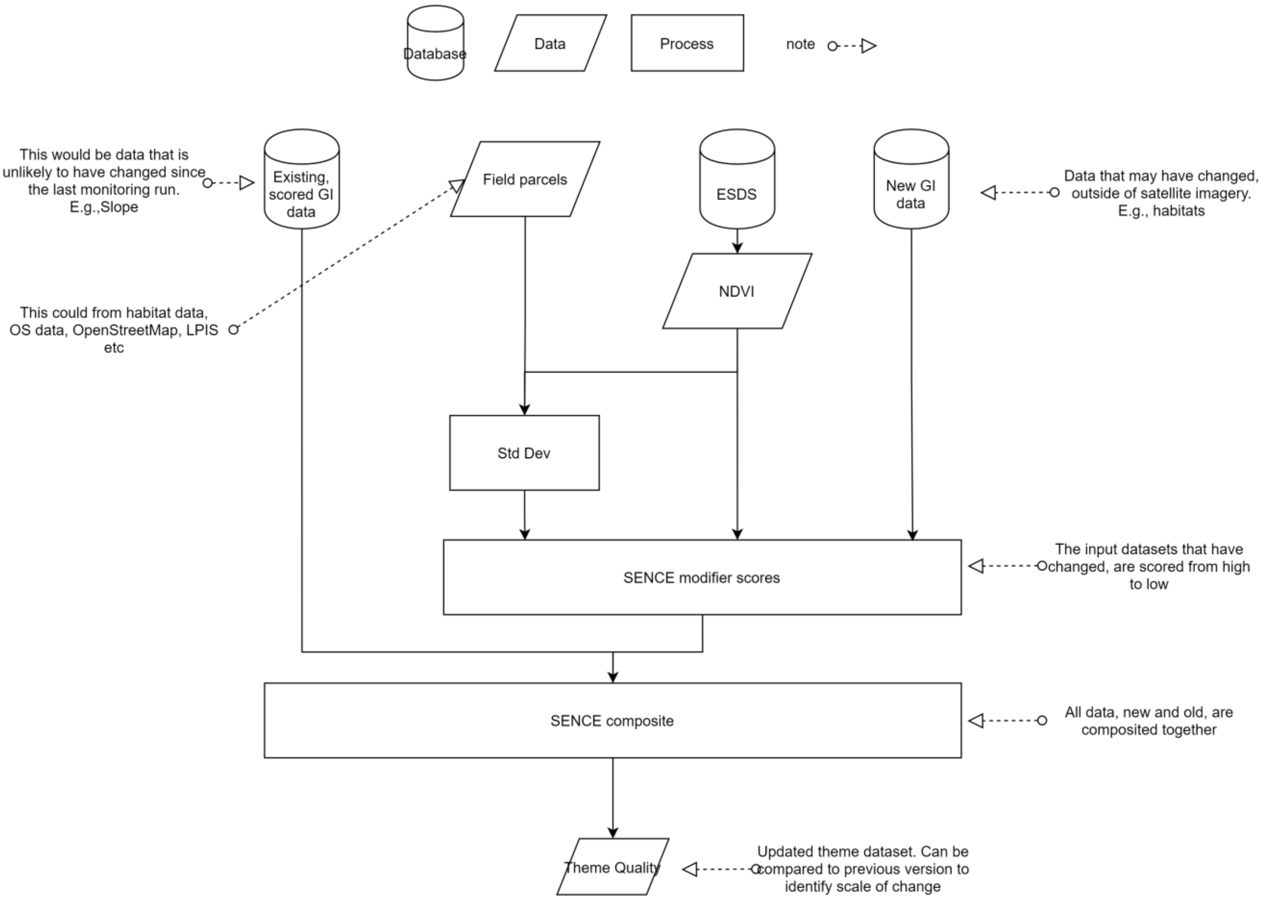

Figure 6-2: Example flowchart of processes, illustrating the integration of new biophysical property datasets (e.g., vegetation productivity) into existing data

Individual optical NDVI captures can play a role in monitoring the levels, specifically for identifying where and when significant changes in land cover occur; for example, the felling of woodland, or the harvesting of crop/silage. The latter is important for the consideration of wader and pollinator nesting/roosting and foraging. When a new NDVI capture is acquired and compared to the previous capture, a significant reduction in values would indicate a loss in vegetation biomass or productivity.

This project has found the benefit of using ARD[1] to create a rich time-series of data that allows for straight forward analysis. It is often more time- and cost-effective to acquire ARD products and services that can be tailored to specific requirements. Developing a cloud-based infrastructure allows for the continual acquisition, processing, and monitoring of Sentinel data, ARD products, and analysis. These can be integrated into existing systems and workflows, and be run at scale.

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[1] Provided by Environment Systems Data Services platform

6.3 Sustaining the Gwent Levels Mapping

An online mapping tool could be developed, to hold and visualise all the data. It is suggested that this becomes a living map project, where any field work, or checking of the map, is immediately incorporated into the data. This web tool will also be useful for partners, stakeholders, and landowners, to better understand their area. Having access to one dataset means that any partner organisation can have easy access, and therefore the data is not siloed, and can easily be reproduced and repurposed. It is suggested that reference documents, such as an Atlas, are prepared periodically in case of any technical faults that prohibit access.

7 Recommendations and the Way Forward

7.1 Habitat data

There are some primary ways by which the baseline habitat mapping accuracy could be enhanced.

The habitat data has used broad habitat classes, some of which can be divided into further sub-classes, but may not necessarily be analysed with the accuracy or consistency of the classes used in this study. In most cases, the sub-classes are defined on the biophysical properties of the parcels, such as vegetation productivity and species richness, which are already considered as integrated, and easily monitored, ARD inputs into the theme models.

The habitat data's accuracy could be further enhanced through additional manual interpretation, which could focus on features with possible inaccuracies, such as silage and arable fields; or input data known to have been collected a sufficiently long time ago to leave changes in land use to be expected, such as the National Forest Inventory.

It is recommended that the habitat data is kept regularly up-to-date, rather than re-mapped on a periodic basis. This can be achieved through the manual interpretation of imagery, or though the identification of potential change which can be checked in the field or using recent imagery. A fully-automated updating process is feasible using machine learning and Earth observation imagery, though this requires extensive training data. After a few iterations of habitat updates, it is possible to incorporate stable habitats as training data, reducing the requirement for field surveys.

7.2 Ecosystem service modelling

The key themes for this study have been modelled based on the principles of the SENSE methodology; where scored input datasets are combined based on scientific knowledge and expert opinion. The SENSE methodology functions particularly well in data-poor regions - including training data.

Due to SARS-CoV-2, it was not possible to gather ground survey data to train the theme models, instead relying on expert and local knowledge on each of the key themes. It is recommended that in future iterations, survey data on the key themes is incorporated into the models, to tie in real-world observations alongside the scientific and expert knowledge, and fine-tune the scoring of the input datasets.

7.3 Monitoring

At its most basic level, monitoring going forward would entail regular updates to the habitat data and EO-derived indices, which would then be used to update all the key theme models. From a remote sensing perspective, these updates could be driven by Environment Systems' Satellite Data Services platform, as this would allow for easy access to up-to-date satellite imagery analytics.

As the habitat classes were kept broad and the models rely more on the biophysical properties of the vegetation, the monitoring would be more cost-effective as it only has to track satellite-driven indices. This can be fully automated, rather than having to first undergo a habitat classification, which would require ground survey training and validation data. Regardless, it is recommended that any habitat data sourced is kept as up-to-date as possible.

If, since the last update, habitat restoration projects have taken place within the Gwent Levels, the imagery could also be used to assess which of the restoration sites appear to be on a good trajectory for reaching their objective, and which might require field visits to ensure the habitat on the site is developing as desired.

During update cycles, it would also be possible to amend rule-bases to accommodate more recent scientific findings and survey data, altered conservation objectives, or alter priorities with regards to ecosystem service generation.

There is a potential for the inclusion of citizen science applications, which can be of high value where features can be distinguished without specialist training. The created dashboard could, for example, be upgraded to be able to receive feedback from visitors to the Levels on the habitats, or upload geotagged photos. This information could then be used to update the habitat map, as well as provide feedback where certain species of interest have been located.

7.4 Dashboard

Dashboards are web-based visual displays that allow for the presentation of complex, spatial data, to a wider audience. They are easy to use by non-professionals, and can be designed to include data-driven map layers, lists, charts, gauges, and indicators. They can also be interactive, allowing the user to pan and zoom into areas of interest, with selected items also changing depending on where in the map extent the user is.

Using the Gwent Levels as an example, the home screen could be set to the extent of the Levels themselves, with charts representing the proportion, or hectares, of suitable wader habitats. The user could then navigate to a particular area of interest of theirs, such as a farm holding, and the information and values from within the farm boundary would change depending on what the map is showing.

The data that is hosted within a dashboard can be fed in automatically from the cloud, and therefore be kept up-to-date at all times with new satellite image captures. They can therefore play a key role is visualising and interrogating the data from any monitoring system put into place.

7.5 Scaling

SENCE is a highly flexible and scalable tool, designed to support assessment of ecosystem services, common as well as specialised ones, in a wide range of biomes, while also offering great repeatability once a rulebase for a specific service / biome is established.

The Sentinel satellite programs allow science-grade products to be easily incorporated into automated routines that can be analysed at scale, when required. The 10 m spatial resolution, high frequency capture rate, 110 km imagery, and the proposed continuity missions, make them ideal for the base, and subsequent, data for monitoring systems, not just for Gwent, but nationwide.

Specifically, this means that:

- The services mapped for this project could efficiently be repeated for other landscapes.
- Landscapes and protected areas with differing main environmental and conservation objectives could have these objectives reflected through small adjustments to the rule bases
- For landscapes and protected areas with a different set of priority species, rulebases can be added or adjusted to reflect these. For example, while the Gwent Levels prioritises wetland bird species, another landscape might be interested in woodland species.
- While good data on a range of factors guarantees the best modelling outputs, SENCE has specifically been designed to function in data-poor regions, or regions with a patchwork of different datasets.
- Data poor vs data rich: the more accurate in scale, the more recently captured, and the more complete in coverage the underlying data sets are the more precise the resultant ecosystem service maps SNECE produces.
- The modelling can be re-run at future times for monitoring
- Using the SENCE approach, this project has specifically been designed for the integration of Sentinel data as individual input resources. This makes it an ideal method for routine updates, and the ability to automate the entire process.

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9 Appendix A: Biophysical factors used to assess quality models

Biophysical property	Lapwing nesting	Lapwing foraging	Shrill carder bee nesting	Shrill carder bee foraging
Arable	Very high	Very high	Low	Low
Broadleaved	Very low	Very low	Low	Moderate
Built-up areas	Very low	Very low	Very low	Very low
Conifer	Very low	Very low	Low	Moderate
Drain/Reen	Very low	Very low	Very low	High
Hedgerow	Very low	Very low	Low	Moderate
Grassland	Very high	Very high	Very high	High
Open water	Very low	Very low	Very low	Moderate
Open water inland	Very low	Very low	Very low	High
Saltmarsh	Very high	Very high	Very high	High
Scrub	Very low	Very low	Low	Moderate
Slope	-	-	-	-
Productivity	Less	More	Less	Less
Floristic diversity	More	Less	More	More
Canopy height	Less	Less	Less	Less
Hedge width	Less	Less	More	More
Water pooling	Less	Less	Less	Less
Tidal inundation	Less	Less	Less	Less
Canopy/sward structural diversity	Less	More	More	More
Distance from hedgerows	Further	Further	Closer	Closer
Distance from woodlands	Further	Further	Closer	Closer
Distance from urban	Further	Further	Further	Further
Agricultural intensity	Less	Less	Less	Less

Biophysical property	Lesser horseshoe roosting	Lesser horseshoe **foraging**	Pipistrelles roosting	Pipistrelles **foraging**	Noctule roosting	Noctule **foraging**
Arable	Very low	Very low	Very low	Very low	Very low	Very high
Broadleaved	Low	Very high	Very high	Very high	Very high	Very high
Built-up areas	High	Very low	High	Very low	Low	Very low
Conifer	Very low	Moderate	Very low	Moderate	Very low	High
Drain/Reen	Very low	High	Low	High	Very low	High
Hedgerow	Very low	High/Very high	Low	Very high	Very low	High
Grassland	Very low	High	Very low	Moderate	Very low	Moderate
Open water	Very low	Low	Very low	Low	Very low	Low
Open water inland	Very low	Moderate	Very low	High	Very low	High
Saltmarsh	Very low	High	Very low	High	Very low	High
Scrub	Very low	High	Low	High	Very low	High
Slope	-	-	-	-	-	-
Productivity	Less	Less	Less	Less	Less	Less
Floristic diversity	More	More	More	More	More	More
Canopy height	Less	Less	Moderate	Moderate	More	More
Hedge width	More	More	More	More	More	More
Water pooling	Less	Less	Less	Less	Less	Less
Tidal inundation	Less	Less	Less	Less	Less	Less
Canopy/sward structural diversity	More	More	More	More	More	More
Distance from hedgerows	Closer	Closer	Closer	Closer	Closer	Closer
Distance from woodlands	Closer	Closer	Closer	Closer	Closer	Closer
Distance from urban	Further	Further	Further	Further	Further	Further
Agricultural intensity	Less	Less	Less	Less	Less	Less

Biophysical property	Aquatic habitats	Landscape structure	Water quality	Vegetation carbon	Soil carbon
Arable	-	Very low	Very low	0/High	Very low
Broadleaved	-	Very high	High	Very high	High
Built-up areas	-	Very low	Very low	Very low	Very low
Conifer	-	High	Low/Very high	High	Low/Very high
Drain/Reen	-	Low	High	Very low	Very low
Hedgerow	-	Moderate	Moderate	Moderate	Moderate
Grassland	-	Low	Very low/Very high	Moderate	Low/Very high
Open water	-	Very low	Low	Very low	Very low
Open water inland	-	Very low	Mod/Very high	Very low	Very low
Saltmarsh	-	Low/Very high	Moderate	High/Very high	Mod/Very high
Scrub	-	Moderate	Moderate	Moderate/Very high	Low/Very high
Slope	-	-	Shallow	Shallow	Shallow
Productivity	Less	Less	Less	Less	Less
Floristic diversity	More	More	More	More	More
Canopy height	Moderate	More	More	More	More
Hedge width	Less	More	More	More	More
Water pooling	-	-	More	-	-
Tidal inundation	-	-	-	-	-
Canopy/sward structural diversity	More	More	More	More	More
Distance from hedgerows	-	-	Closer	-	-
Distance from woodlands	-	-	Closer	-	--
Distance from urban	-	-	Further	-	
Agricultural intensity	Less	Less	Less	Less	Less

10 Appendix B: Biophysical factors used to assess risk models

Table 10-1: Data and relative erodibility scores used for erosion risk modelling

Dataset	Category	Erosion vulnerability score
Habitat	Arable	Very high
	Broadleaved	Very low
	Built-up areas	Not applicable
	Conifer	Moderate
	Grassland	Moderate
	Mire, fen and swamp	Very low
	Open water	Not applicable
	Road	Not applicable
	Reens/ditches	Not applicable
	Saltmarsh	Very low
	Scrub	Low
	Standing water	Not applicable
Productivity	Low	Low
	Moderate	Moderate
	High	High
Floristic diversity	Low	High
	Moderate	Moderate
	High	Low

Table 10-2: Data and relative scores used for carbon risk modelling

Dataset	Category	Carbon risk
Habitat	Arable	Very high
	Broadleaved	Very low
	Built-up areas	Not applicable
	Conifer	Moderate
	Grassland	Moderate
	Open water	Not applicable
	Road	Not applicable
	Reens/ditches	Not applicable
	Scrub	Low
	Standing water	Not applicable
Erosion risk	Low	Low
	Moderate	Neutral
	High	High
Agricultural intensity	Low	Low
	Moderate	Neutral
	High	High

11 Appendix C: Opportunity Interaction Matrix

3	Strong positive impact
2	Positive impact
1	Slight positive impact
0	Negligible
-1	Slight negative impact
-2	Negative impact
-3	Strong negative impact

Theme	**Opportunity**	Wader habitats	Pollinator habitats	Short-range bat habitats	Medium-range bat habitats	Long-range bat habitats	Connected & overgrown	Not connected &overgrown	Enhance water quality	Connect woodland	Tree removal	Tree planting	Arable conversion	Rewetting
Waders	Wader habitats		1	0	1	1	0	0	1	-3	1	-3	3	3
Pollinators	Pollinator habitats	3		0	2	1	0	0	1	-3	3	-3	3	1
Bats	Short-range bat habitats	-2	2		1	1	-2	-2	2	3	-3	3	-2	1
	Medium-range bat habitats	-1	2	3		3	-2	-2	2	3	-3	3	-2	1
	Long-range bat habitats	1	3	2	3		-2	-2	3	3	-3	3	-2	2
Aquatic	Connected & overgrown	0	0	1	1	1			1	-2	3	-3	-3	-2
	Not connected &overgrown	0	0	1	2	3			1	-2	2	2	-3	-2
Water Quality	Enhance water quality	2	3	2	2	2	-1	1		1	-1	1	2	1
Landscape structure	Connect woodland	-3	1	3	3	3	1	1	3		-3	3	1	1
	Tree removal	3	-2	-3	-3	-3	2	2	-3			-3	1	1
Carbon	Tree planting	-3	2	3	3	3	-2	-2	3	3	-3		3	2
	Arable conversion	3	3	3	2	2	-1	-1	1	1	-1	1		2
	Rewetting	3	2	3	3	3	-1	-1	2	2	-1	2	3	

12 Appendix D: Scenario descriptions and adjustments

Scenario	Representation
High nature value	Buffer zones maintained alongside water courses and managed as part of a diverse seed rich /flower rich habitat
	Ditch recasting from previous years creates disturbed ground comprising composite species
	Cleaner water and air through reduced agricultural pollution.
	Greater carbon storage in semi natural habitats
	Reduced flood risk in adjacent urban areas through increased water holding capacity of restored ditch network, slowed flow of surface water by increased surface roughness as semi natural habitats develop and increased infiltration through greater heterogeneity of vegetation.
	Increased ecosystem resilience as connectivity of habitats is improved across the landscape.
Status Quo	Farm businesses struggle to adapt to ever diminishing returns and so look to alternative sources of income such as solar farms or selling land for development.
	The traditionally gripped fields are lost to modern farming methods. Wet field ditches, too costly to maintain, are neglected and over time, hedges form
	Water quality continues to deteriorate through diffuse pollution
	Constant encroachment on the landscape of development pressures as developers view ‘open season’ on the landscape (not sure what you are modelling here pressures in general from housing/industry everything?)
Intensification	Loss of pastoral diversity and with it, insect life, as intensive agriculture takes over
	Watercourses are overwhelmed with nutrient as farmyards struggle to manage run-off
	Landscape features including ditches, orchards, hedgerows, wet grasslands and reedbeds are lost as land is improved to increase productivity.
	The species and habitats that made the Gwent Levels special are lost and designation is removed, leading to increased development.

	Reduced air and water quality from agricultural pollution, along with reduced use of the landscape for recreation due to poor environmental quality impacts negatively on the health of adjacent communities.
	Poor water quality due to diffuse pollution impacts on adjacent designated sites including the Rivers Usk and Severn.
	Poor environmental quality means people move out of the area and communities are abandoned; land is given over to development further reducing the quality of the environment.
	Poor condition of soil and water means agriculture is unsustainable due to excessive amounts of inputs required and more land is sold for development.
	Lateral run-off from development reduces the effectiveness of the watercourses to mitigate flash flood events
	The 2,000 year old extensive grasslands and all their archaeological value are lost forever under concrete as development continues.

13 Appendix E: Further Considerations for a Living Map

- The acquisition and processing of satellite imagery can be difficult for non-experts. It may be beneficial to use dedicated data services and portals[2] that provide analysis-ready data designed for non-technical users.
- The spectral bands used for the spectral analysis can vary depending on the task.
  - Near-infrared bands are advised for looking at the different species composition
  - Vegetation indices, such as Normalised Difference Vegetation Index (NDVI) are advised for looking at differences in vegetation condition and productivity.
  - Principle Component Analysis (PCA) is a technique generally applied to multispectral imagery, to transform multiple bands of information to one that represents most of the information present in the original dataset.
- If there are less than 50 polygons in a habitat class, the practicality and reliability of the change detection analysis is significantly reduced
  - If there are less than 30 polygons within a habitat class, it is suggested that all sites of that class should be checked in the field or against recent imagery.
- The steps above can be scripted and chained together into an automated workflow.
- Checks can take place either via aerial photographic interpretation (API) or field survey.
  - Older imagery can often help to decide if genuine change has taken place.
  - A discussion on the merits of checking possible omission error in polygons not flagged as changed is recommended.
- To ensure continuity and maintain the lineage, it is important to attribute any change with the name of the surveyor, the date of the edit, and method that the change was assessed (e.g., through site visits, manual interpretation etc).

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[2] Such as https://data.envsys.co.uk