

Terrestrial and freshwater Resilient Ecological Networks: a guide for practitioners in Wales

NRW Evidence Report No. 483

Garrett HM, and Ayling SC.

March 2021

Natural Resources Wales

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In producing this guidance, a consultation process was held for NRW staff and external partners. Their valuable comments and insights have been incorporated into the final version of the document.

The members of the Ecosystem Resilience and Restoration Task and Finish group were three NRW staff: Heather Garrett, Sarah Ayling and Rebecca Wright, and Jon Walker, University of Swansea, and Adam Rowe, South East Wales Biological Records Centre.

Crynodeb Gweithredol

Mae'r canllaw ymarferol hwn ar gyfer pobl yng Nghymru sy'n gweithredu polisiau a phrosiectau amgylcheddol a fydd yn gwella ac yn cynnal cadernid ein hecosystemau. Mae'n esbonio dilysrwydd defnyddio'r cysyniad o rwydweithiau ecolegol cadarn fel sylfaen ar gyfer gweithio mewn partneriaeth ar gyfer rheoli ein hadnoddau naturiol yn gynaliadwy (SMNR) mewn ffordd integredig. Mae'r dull hwn hefyd yn cefnogi defnyddio atebion ar sail natur pan fo'n bosibl i gyflawni'r amcanion hynny a helpu i adfer natur.

Mae offer cynorthwyol ar gyfer datblygu prosiectau lle mae rhwydweithiau ecolegol cadarn yn ffurfio strategaeth graidd yn cael eu darparu ar ffurf cyfres o gamau manwl i gynorthwyo penderfyniadau, rheolau ecolegol synnwyr y fawd a chyfeiriad teithio er mwyn gwella cadernid ecosystemau. Darperir rhestrau o adnoddau defnyddiol er nad yw'r rhestr yn un gyflawn, ac efallai bod tystiolaeth ychwanegol, offer ac adnoddau eraill ar gael.

Executive summary

This practical guide is for people in Wales who implement environmental policies and activities that will enhance and maintain the resilience of our ecosystems. It explains the validity of using the concept of Resilient Ecological Networks (REN) as the foundation for working in partnership for the integrated sustainable management of our natural resources (SMNR). This approach also supports using nature-based solutions (Nb-S) where possible to achieve those objectives and aid nature recovery.

Support tools for project development where Resilient Ecological Networks form a core strategy is provided in the form of a detailed stepwise decision-support framework, ecological rules of thumb and direction of travel for improving ecosystem resilience. Lists of helpful resources are provided although they are not exhaustive and additional evidence, tools and other resources may be available.

Resilient Ecological Networks: creating resilient landscapes for people and wildlife

The audience for this guide

This practical guide is for people in Wales who want to implement environmental policies and support sustainable activities that will enhance and maintain the resilience of our ecosystems. It explains the validity of using the concept of Resilient Ecological Networks (REN) as the foundation for working in partnership for the integrated sustainable management of our natural resources (SMNR). This approach also supports the use of nature-based solutions (Nb-S) where possible to achieve those objectives and aid nature recovery.

What's in this guide

This guide shows how to use the NRW framework for understanding aspects of ecosystem resilience (the DECCA framework), and ecologically based “rules of thumb” to design Resilient Ecological Networks in the landscape. In addition, the stepwise decision-support framework, based on the nine principles of SMNR, facilitates the production of a plan with clear objectives that prioritise the most effective actions to build ecosystem resilience.

Checklists and links to relevant open-access resources are provided to aid in the planning and delivery process.

How this guide was produced

This guide is based on the recent Natural England (NE) research report *Nature networks: a summary for practitioners* (Crick *et al*, 2020a). It is a summary based on the extensive review of evidence presented in the Nature Networks Evidence Handbook by Natural England (Crick *et al*. 2020b) and aims to provide a quick reference guide to support the development of ecological networks, known as Nature Networks, in England. With the authors' permission we have borrowed text from their practitioners' guide where appropriate and adapted sections to suit the Welsh science–policy context to create this guide for practitioners in Wales. We are grateful to the authors' willingness to share their good practice and permission to adapt their guide.

The guide for Wales has been produced in consultation with colleagues from Natural Resources Wales, Welsh Government, environmental non-governmental organisations (eNGOs) and academics in Wales.

Welsh legislation for the sustainable management of our natural resources

Under the Environment (Wales) Act 2016, NRW and other public bodies should seek to maintain and enhance biodiversity and the resilience of ecosystems and the benefits they provide both now and for future generations. This objective will be aided by applying the principles of the sustainable management of natural resources (SMNR).

The Natural Resources Policy (NRP) (Welsh Government, 2017) is designed to drive the delivery of the goals of recent legislation known as the Well-being of Future Generations Act (WFG Act) and the Environment (Wales) Act (Welsh Government, 2015; 2016). This policy document and the Nature Recovery Action Plan (Welsh Government, 2020) state the need to proactively develop Resilient Ecological Networks to maintain and enhance the wider resilience of Wales' ecosystems. In doing so, Wales would also address the Convention on Biological Diversity's Strategic Plan for Biodiversity and the associated Aichi biodiversity targets.

At the local level Area Statements facilitate the implementation of the NRP and integrate the SMNR approach. Seven Area Statements have been published by Natural Resources Wales (NRW, 2020c); each one outlines the local key challenges, what we can all do to meet those challenges, and how we can better manage our natural resources for the benefit of future generations.

The National Development Framework (NDF) is due for publication as "Future Wales: the national plan 2040" in early 2021 (Welsh Government, *in prep*). Policy 8 in the draft NDF consultation document (Welsh Government, 2021), states that a strategic framework for biodiversity enhancement and ecosystem resilience is required. The framework will identify:

- areas which could be safeguarded as contributing to ecological networks for their potential importance for adaptation and mitigation to climate change or other pressures, for habitat restoration or creation, or which provide key ecosystems services, to ensure they are not unduly compromised by future development;
- opportunities where strategic green infrastructure could be maximised as part of development proposals, requiring the use of nature-based solutions as a key mechanism for securing sustainable growth, ecological connectivity, social equality and public well-being.

The draft NDF plan states that planning authorities should include these sites in their green infrastructure assessments, development plan strategies and policies in order to promote and safeguard the functions and opportunities they provide. In all cases, cumulative action towards securing the enhancement of biodiversity and the resilience of ecosystems should be demonstrated as part of development proposals through innovative, nature-based approaches to site planning and the design of the built environment.

Definition of ecosystem resilience

NRW works to the definition of ecosystem resilience from the State of Natural Resources reports (NRW, 2016; 2020a), which is “the capacity of ecosystems to deal with disturbances, either by resisting them, recovering from them, or adapting to them, whilst retaining their ability to deliver services and benefits now and in the future” (Disturbances are interpreted to mean pressures and demands on the ecosystem).

In a recent scientific literature review by NRW staff (Garrett, 2020), it was confirmed that directly quantifying resilience is difficult because ecosystems are complex and dynamic. One pragmatic approach is to think about the relationship between attributes of ecosystem resilience and their emergent properties as indicators of resilience (Figure 1). Ecosystems have many attributes but the most easily understood and assessed are diversity, extent, condition and connectivity. Attributes and emergent properties are both aspects of ecosystem resilience which is described as adaptability and/ or the ability to recover or resist change in response to pressures either over a long or short time period. These emergent properties are less easily measured or assessed but give rise to the overall quality of ecosystem resilience. We use the initials of the measurable attributes and the emergent properties to describe this concept as the DECCA framework for ecosystem resilience.

Figure 1 illustrates the relationship between the attributes, aspects and ecosystem resilience.

Diversity

Diversity matters at every level and scale, from genes to species, and from habitats to landscapes. It supports the complexity of ecosystem functions and the cascade of interactions that deliver services and benefits, so diversity is important for enhancing the capacity of the whole system to adapt to future change.

Extent

Extent or the size of an ecosystem will affect its capacity to adapt, recover or resist disturbance. Fewer species can survive in a smaller patch, and the demography of species is altered when habitat is lost, leading to species loss and ecosystem decay.

Condition

The condition of an ecosystem is affected by multiple and complex pressures acting both as short term “pulse” and longer term “press” types of disturbance that affect the resilience of ecological communities and their capacity to resist, persist or recover. (Bender *et al*, 1984). The pressures can disturb both the biotic (biological) and abiotic (environmental) factors associated with a habitat or species.

Connectivity

Connectivity refers to the links between and within habitats, which may take the form of physical corridors, stepping stones in the landscape, or patches of the same or related vegetation types that together create a network that enables the flow or movement of genes, species and natural resources (often referred to as an “ecological functional network”). Environmental factors such as geology, soil type or hydrological links affect sea or landscape connectivity. For any given species, connectivity is related to the relative distance that species can move to feed, breed and complete lifecycles that may need different environments.

Aspects of ecosystem resilience

Ecosystem resilience is regarded as a product of the above four attributes, and their emergent properties of adaptability, resistance, or recovery from pressures and demands. The initials of the measurable attributes and the aspects to describe this concept as the DECCA framework for ecosystem resilience. Adaptability was previously listed as an attribute of resilience (NRW, 2016), but our understanding has become more refined and Figure 1 clarifies the relationships of these terms.

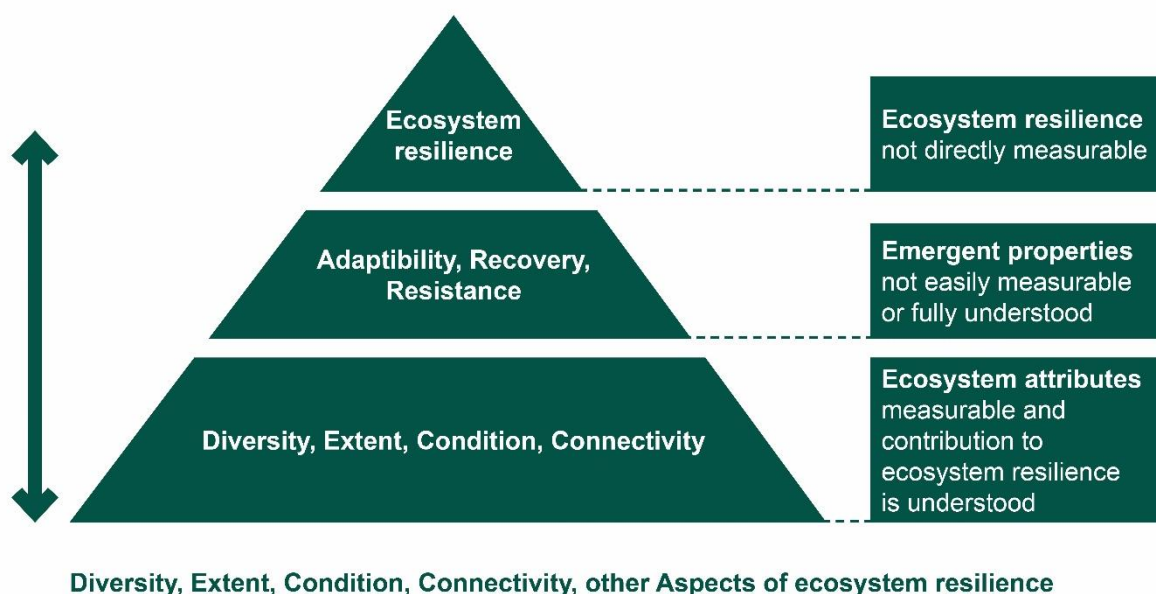


Figure 1: DECCA framework showing the relationship between the attributes and the emergent properties of resilience.

The DECCA framework can be used to:

- Select the most effective types of data to be considered within the evidence base and monitoring strategies of policies, plans and programmes, for example, the State of Natural Resources Report (SoNNaR) (NRW, 2020a).
- Ensure that ecosystem resilience is properly considered within policies, plans and programmes.
- Design effective and prioritised programmes that help build ecosystem resilience including, for example, advice given through sustainable landscape-scale activities.

Assessment of ecosystem resilience in Wales

Assessing ecosystem resilience is complex, NRW's most recent assessment to detect patterns emerging across the national landscape was done by collating expert judgement for each ecosystem (NRW, 2020a). There is no method for quantifying baseline or absolute resilience so ratings of low, medium and high were given to each attribute based on the criteria of diversity, extent, condition and connectivity.

It was found that ecosystems in Wales are unlikely to have sufficient resilience to cope with expected and unforeseen change and disturbance, including the challenges of climate change, and so are unlikely to be able to deliver goods, services and benefits into the future. The degree of risk is higher for some ecosystems than others and habitat details are given in the [Ecosystem Resilience chapter](#) of the State of Natural Resources Report (NRW, 2020a).

Definition of Resilient Ecological Networks

The maintenance, enhancement or re-creation of Resilient Ecological Networks are vital for nature recovery and the Natural Resource Policy (NRP) and the draft National Development Framework (Welsh Government, 2015; 2020) picks up this theme at a Wales level when it defines Resilient Ecological Networks (RENs) as

“... networks of habitat in good ecological condition linking protected sites and other biodiversity hotspots across the wider landscape, providing maximum benefit for biodiversity and well-being. Such nature networks have existing or potential for healthy resilient ecosystems which provide a range of important ecosystem services as well as allowing the movement of species across landscapes in response to climate change.”

How a Resilient Ecological Network is a different approach

Much conservation activity to date has focused on selecting the best examples of a habitat within an area for statutory designation and management. These sites' boundaries were largely based on the remaining habitat and not on the ecosystem processes needed to make them resilient and functional into the future. This approach did not fully consider how land-use and environments enable species to travel across the landscape (functionally connectivity) and how this movement can affect ecological processes at many different scales across a landscape. The older approach also did not fully consider the contribution of spatial arrangement of habitats (structural connectivity) to ecological processes and resilience. Regeneration of native woodland is one example of the interplay between these two types of connectivity; the capability of oak trees to naturally regenerate is influenced by the distance acorn burying mammals can range (functional connectivity). Their ranging behaviour is affected by the spatial distribution of suitable habitat that provides cover to avoid predation (structural connectivity).

An integrated habitat network approach aims to identify areas where existing habitat is still functionally and / or structurally connected and the intervening land-uses and environments supports ecological processes (Briers, 2011). The diversity, extent and condition of the habitat network is of equal importance and so in Wales, the Resilient Ecological Networks (RENs) method also incorporates the principles of SMNR and the DECCA resilience framework into their design and management. As such the REN is not framed as a simple nature conservation objective but rather as a means for integrated environmental policy and project management (Vimal *et al*, 2012).

Characteristics of a Resilient Ecological Network

The features of a REN will depend upon the local landscape character and the existing habitats and land-use that make them distinguishable from the wider landscape. These **features** can be classed as either **core areas** or **intervening land use matrix**.

The core area consisting, initially and primarily, of existing high quality semi-natural habitats, would be made up of the following **components**:

- National statutory sites: biological and geological Sites of Special Scientific Interest (SSSI), Geological Conservation Review sites (GCR), National Nature Reserves.
- International statutory sites: Special Areas of Conservation (SAC), Special Protection Areas (SPA), Ramsar wetlands, Biosphere and Biogenetic reserves, and Global Geoparks.

- Non-statutory sites: Sites Important for Nature Conservation (SINCs) which are also known nationally as Local Wildlife Sites, Regionally Important Geological sites (RIGs), and proposed SSSI (pSSSI),
- Priority habitats as identified in Section 7 of the Environment (Wales) Act.
- Veteran trees, Ancient Semi-Natural Woodland (ASNW) and Restored Ancient Woodland Sites (RAWS).

Many of the core areas would be large enough to accommodate a mosaic of different or complementary semi-natural habitats both spatially and through time. They would be big enough to have their own degree of permeability and contain dynamic boundaries and transitional areas. These core areas would form a significant proportion of each REN and would be managed positively to maintain or restore their biodiversity and functional processes, and where appropriate, to enhance their genetic, species and structural diversity.

A RENs approach recognises the fundamental role that protected sites can play in ecosystem resilience, acting as reservoirs of biodiversity which can flow into the wider landscape if conditions allow. But it also recognises that protected sites are vulnerable to a range of pressures and demands. Without functional and structural connectivity, biodiversity within protected sites is unable to move, for example, in response to climate change, resulting in biodiversity loss and a decline in the associated ecosystem services.

The second feature would be an **intervening land-use matrix** that would reinforce and connect the core areas. The matrix would reinforce core areas by restoring, creating and positively managing semi-natural habitat on land adjoining its components to increase their size and so reduce extinction risk, buffering them from edge effects and human impacts.

The intervening land-use matrix would also contain a diverse array of elements providing functional connectivity between core areas and their components. These elements would include landscape features, such as buffers, corridors, stepping-stones and other permeable features, to allow the movement of organisms e.g. for foraging or migration of individuals, through dispersal of seeds and genes, to the major shifts of species' populations to adjust to a changing climate. They would also contain features which allowed for movement within natural processes, for example, cycling of water and nutrients between different components of the landscape.

The **components** of the intervening land-use matrix might include:

- Linear landscape features such hedges, native tree lines, ditches and the vegetated margins of fields, watercourses, hedgerows, roads and active travel routes;
- Stepping stone features such as small native or mixed woodland, land managed as ecological focus areas, in-field trees;
- Other habitat that it is not considered within our current classification system, for example, ffridd (also known as coedcae)¹, scrub, post-industrial landscapes;

¹ An upland fringe habitat at the boundary between historically enclosed farmland and unenclosed uplands, and on rocky knolls and steep slopes within enclosed fields.

- Land supporting degraded semi-natural habitats with potential for restoration such as semi-improved species poor grassland and Plantations on Ancient Woodland Sites (PAWS);
- Habitat in process of restoration from a degraded to a functional state e.g. land in restoration or creation under agri-environment schemes.

Additional designations that could be considered as part of core area or intervening matrix depending on the scale of the design include:

- Area of Outstanding Natural Beauty (AONB), National Park² and Heritage Coast.

These additional designations often have a boundary based on cultural and environmental values whose objectives would complement the REN approach. Practitioners may find that parts can be included as **core areas** whilst other parts may fulfil the role of an **intervening land matrix** as described above. The part played by these designated areas may be as a hybrid of the two features or there may be an ambition for the whole designated area to evolve towards becoming a core one in the future.

Figure 2 shows an idealised integrated habitat network and how the core areas of existing high quality habitat (a and b) and the intervening land-use matrix (c, d, e and f) can be managed holistically to form a Resilient Ecological Network sitting in a wider landscape (g).

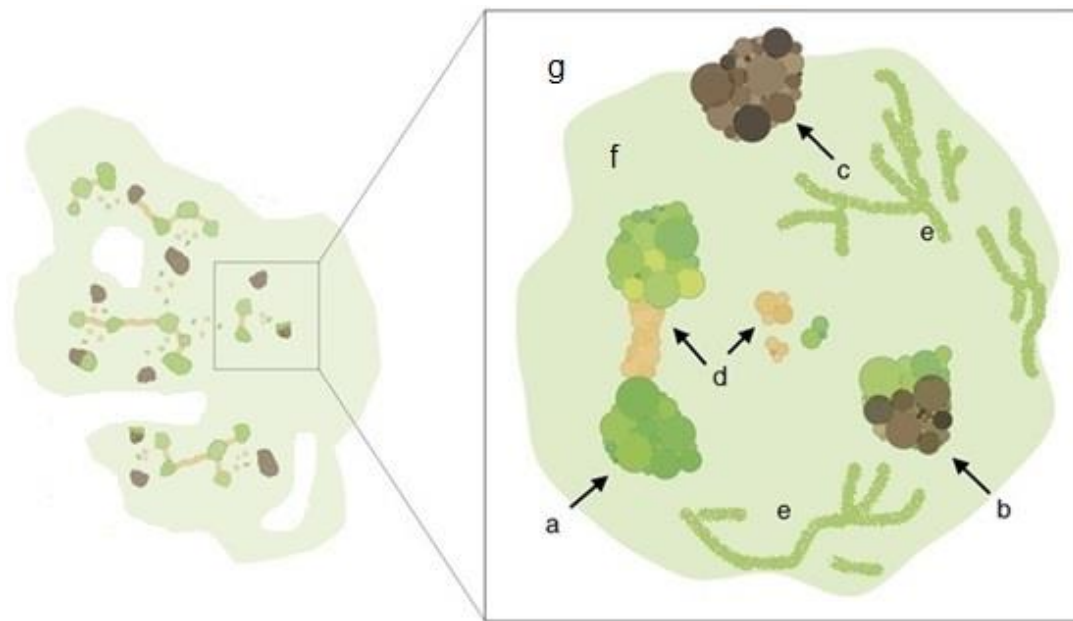


Figure 2: An idealised ecological network (based on Issac *et al*, 2018). Plausible actions to increase network resilience include improving the condition (a) or size (b) of existing habitats, creating new habitats (c), creating features that facilitate dispersal of species and natural resources (d) and softening the intervening land-use matrix (e), intervening land-use matrix (f) and land-use outside of Resilient Ecological Network (g).

² National Park and Areas of Outstanding Natural Beauty (AONB) designations protect areas of exceptional landscape and also include the conservation and enhancement of wildlife and habitats, as components of natural beauty. Both were created under the National Parks and Access to the Countryside Act 1949, but only a National Park has any planning development control powers.

Resilient Ecological Network design and the nine principles of SMNR

These networks form the cornerstone of ecosystem resilience in a landscape and are a key theme for action in the NRAP and in the draft National Development Framework (Welsh Government, 2020; 2021), however, developing a REN is not just a spatial approach to environmental management but also one that involves a cross-section of people (stakeholders) in the planning and design process. This concept aligns with the five ways of working together as specified in the Well-being of Future Generations Act 2015:

1. Adopt a long-term perspective
2. Take an integrated approach
3. Involve citizens
4. Collaborate
5. Pursue a preventative approach

This approach was further developed in the Environment (Wales) Act 2016 to define the nine principles of the Sustainable Management of Natural Resources (SMNR) as the way to maintain and enhance ecosystem resilience and biodiversity, which is the overarching objective of the Act. These are the nine principle of SMNR:

1. **Adaptive management:** to manage adaptively by planning, monitoring, reviewing and where appropriate changing action.
2. **Scale:** to consider the appropriate scale for action
3. **Collaboration and engagement:** to promote and engage in collaboration and engagement.
4. **Public participation:** to make appropriate arrangements for public participation in decision-making.
5. **Evidence:** to take account of all relevant evidence and gather evidence in respect of uncertainties.
6. **Multiple benefits:** to take account of the benefits and intrinsic value of natural resources and ecosystems.
7. **Long term:** to take account of the short-, medium- and long-term consequences of actions.
8. **Preventative action:** to take action to prevent significant damage to ecosystems.
9. **Building resilience:** to take account of the resilience of ecosystems, in particular the following aspects:
 - I. diversity between and within ecosystem,
 - II. the connection between and within ecosystems
 - III. the scale of ecosystems
 - IV. the condition of ecosystems including their structure and function
 - V. the adaptability of ecosystems

The need for connectivity

Connectivity is a broad term and refers to the characteristics of the landscape that affect the movement of organisms and of natural processes. It is usually interpreted with respect to species movement, but actually has much wider implications, and is relevant to ecosystem functioning as a whole and its resilience (Latham *et al*, 2013).

Many of the major issues affecting ecosystem functioning and biodiversity conservation result from the loss and fragmentation of natural habitats. In Wales, the breakdown in ecosystem connectivity has happened over thousands of years as natural habitats have been modified, or replaced by artificial systems and the built environment, however, many severe losses have occurred only relatively recently. Fragmentation can have serious impacts on a wide range of ecosystem functions and services, including nutrient cycling, water quality and management, carbon capture, air quality and pollination (Latham *et al*, 2013).

Stepwise decision-support framework

The design process has three logical steps that might be followed by a partnership wishing to develop a REN in their area (Crick *et al*, 2020a). There are key tasks associated with each step to help identify priorities and keep the programme on track. The three main steps are to:

1. understand the place,
2. create a vision and plan to build resilience through creating networks that reflect the landscape character,
3. organise the project delivery.

NRW staff used SMNR principles to design a place-based process for producing Area Statements (NRW, 2020c). The lessons learned from those processes could be used to develop methods for creating the vision and the delivery of the networks through landscape planning.

When implementing a plan for a REN, the planning system is a major statutory instrument that can be used to help implement appropriate land-use within and adjacent to a network. Partnerships may need to familiarise themselves with the Green Infrastructure guidance published by NRW (Elliott, *in prep*), the requirements of their local development plan and Planning Policy Wales guidance (currently PPW10).

Step 1 Understand the place

Key task: Audit of natural resources, plans and the legislative context

Identify what the area is special for, from a national and local perspective, how nature has changed and the potential for its restoration. This assessment should include [biodiversity](#) (including priority habitats and species), [geodiversity](#), [landscape character](#), [the role of protected areas](#) and the influence of the [cultural and historical environment](#).

Agree an initial area of search for further information gathering. Individual, or groups of, Landscape Character Areas, or other landscape designations such as Areas of Outstanding Natural Beauty or National Parks, can act as a geographical framework to help define the Area of Search.

It is also advisable to create a buffer around the initial area of search to help consider whether its extent is appropriate and to identify and align with complementary activity that may be occurring in adjacent areas. It is worth considering how natural ecosystem processes operate across the wider area so that nutrient flows, movements of biodiversity and the potential for pressures from human activity from outside the area might have positive or negative impacts.

Projects should also identify evidence gaps, assess their impact and consider time-limited actions to overcome high impact data deficiencies, for example, such information may be obtained through the environmental impact assessment process.

[Checklist 1](#): Collate relevant national policy objectives for context.

[Checklist 2](#): Describe and map physical and biological information at an appropriate scale

Include statutory and non-statutory sites, priority species and habitats, Level 2 habitat networks (Latham *et al*, 2013), and landscape sensitivity assessments. Information about designated sites will be available from NRW's stakeholder portal which is currently under development [March 2021].

[Checklist 3](#): Collate all existing management plans and strategic objectives, including any existing or previously completed landscape scale initiatives. Check for compatibility between them. Do they effectively frame national policy objectives in the local context?

[Checklist 4](#): Environmental standards and good practice

[Checklist 5](#): Tools and guidance for developing stakeholder and public engagement

Key task: Scope the issues and benefits

Conduct an initial assessment of the REN at an appropriate scale using the DECCA attributes. Clearly define the main issues.

[Checklist 6](#): Describe pressures, drivers, impact and opportunities for change (positive and negative). Clearly define the main issues, refer to the SoNaRR 2020 national resource risk registers (NRW, 2020b).

[Checklist 7](#): Describe ecosystem services: provisioning, cultural and regulating. Clearly define the main issues. Collate historic environmental and cultural features.

Key task: Review the place audit

Review whether the initial area of search chosen remains appropriate in light of the information gathered under Check lists 2-7, adjust area of search if required and gather additional information for an extended area.

Consider current national and local area priorities to identify opportunities and benefits from addressing the issues using the following key questions:

Question 1. Which existing landscape components might already contribute to the REN, and how? Which landscape components that could contribute to an effective REN are missing or could be improved through habitat maintenance, restoration or creation?

Question 2. Are there any significant constraints to the functioning of the components?

Examples of components include key semi-natural habitats and features, important species populations including migratory ones, and the condition of designated sites.

Question 3. What opportunities are there for new or enhanced ecosystem service provision? Which options will potentially tackle the issues and build on opportunities?

Question 4. Which actions deliver the most benefits?

Key task: Scope stakeholder engagement

Develop a stakeholder list or map (if appropriate) based on land ownership and occupancy, local cultural practices, current and potential future ecosystem service suppliers, beneficiaries and purchasers. Ensure that the scope and type of engagement reaches a wide variety of groups. The International Association for Public Participation has developed a framework for understanding the depth and scope of engagement. This is based on five levels of engagement, each one with increasing levels of participation and involvement. At one end of the spectrum, engagement is simply an information-sharing exercise, for example through the provision of websites or newsletters. At the other end, engagement can lead to genuine community empowerment and local control. The scope and types of engagement will be influenced by who is involved.

The stakeholder list could include:

- countryside-access user groups
- developers (who might access Community Infrastructure Levy)
- environmental groups
- landowners, including farmers and land managers
- local media
- local naturalists and environmentalists
- local resident groups – be sure to draw from across the population demographic and those who support outdoor activities for physical and mental and well-being.
- community councils
- politicians in the area (local and national);
- private sector and public utility businesses including tourism, water resources, timber, fibre and food production. Identify those who might be able to support activity.
- local authority stakeholders

Understanding the place and its components

When developing a plan to implement a REN it is important to consider the constraints and opportunities provided by the landscape, biodiversity, geology, and soils of the area. Taking account of these aspects will secure the sustainability of the network and the ecosystem services they provide. In addition, this approach will maintain or restore ecosystem functionality and processes that underpin resilience.

Understanding place and the role of landscape character

Landscapes are a result of the way that different components of our environment – both natural and cultural – interact and are perceived by us. By understanding the landscape components and their interaction, we can understand ecological issues and opportunities, and identify ways to facilitate local support for the changes that establishing a REN may involve.

Shaped by nature and people over time, landscapes form the environmental settings in which we live, work and enjoy life. They contribute to our quality of life, prosperity and well-being. Based on LANDMAP, these characteristics have been described and the national landscape character area (NLCA) maps based on 48 individual character areas are available on-line.

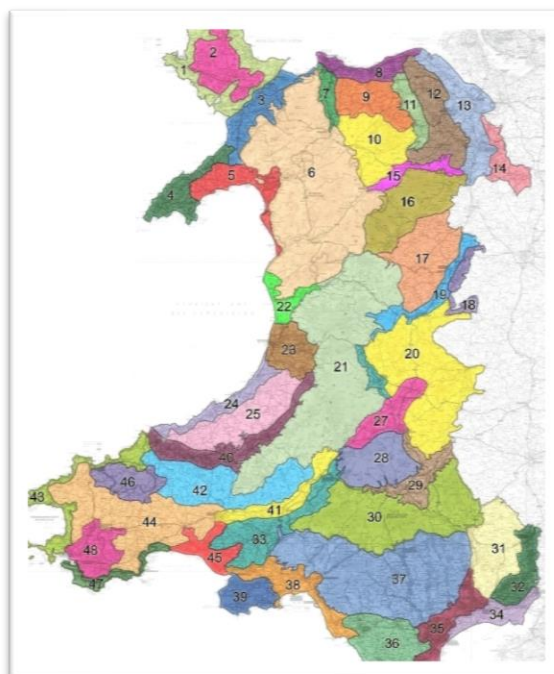


Figure 3: Map showing the national landscape areas of Wales.

NLCAs also contain short narratives capturing visual, geological, habitat, historic and cultural influences and form an ideal resource for working at a strategic level and providing a wider context (1:250,000 scale). There are other, more detailed but smaller scale Local

Landscape Character Areas in Wales too. These are published by local authorities and may form part of their Supplementary Planning Guidance.

Understanding place and the role of geology and soils

Geodiversity is an important part of a REN as it has a direct influence on the diversity of habitats and species and provides a range of natural processes essential to functioning ecosystems, and wider ecosystem services that include carbon capture and natural flood regulation.

Soils form as a result of the interaction between the underlying geology, climate, management, and the vegetation and its decomposing organic matter. They are good markers of previous habitats and land-use and help to define which ecosystems can be restored. As soils develop structure, they carry out complex interactive processes, mediated by soil organisms, including cycling of carbon, fixation of nitrogen, and mediating the flow and quality of water. These processes are fundamental to many ecosystems, their services and most land-use activities.

Soils are habitats for many thousands of species ranging from single-celled organisms to larger invertebrates and plants. It is estimated that more than 1 in 4 of all living species on earth is a strictly soil-dwelling organism (Decaëns *et al.* 2006). Soils are thus an important component of any nature-based network and they can also provide added value to RENs through their ecosystem services, including water purification, water storage, flood alleviation, carbon storage and growing crops, biofuels and timber.

Understanding the place and the role of biodiversity and core areas

Biodiversity is organised into complex ecological networks of interacting species in local ecosystems within which there is a complex interplay of patterns and processes. Species traits, for example, body size, dispersal ability, play an important role in determining how networks respond to drivers for ecosystem change (Hagen *et al.*, 2012).

The Welsh countryside contains a range of both modified and important semi-natural habitats including woodland, semi-natural grassland, heathland, fen, bog, dune, saltmarsh, and a diverse range of upland and montane habitats (Manzoor *et al.*, 2019). So in a diverse and ecologically sensitive landscape like Wales, it is essential to understand the traits and dispersal properties of species populations, and how well their needs are met through the temporal and spatial distribution of these semi-natural and modified habitats such as forestry and agriculturally improved grazing pasture.

Ecological networks have the greatest benefit for species which are sensitive to habitat fragmentation, for example, species with a moderate dispersal capability and a requirement for large areas of habitat. The benefits for individual or taxonomic groups of species with very poor or very good dispersal is less significant. Where priority species or taxonomic groups with the latter dispersal characteristics are identified within the project area of search, then approaches which emphasise improving or restoring existing habitat quality may be more appropriate.

Protected areas will play an important role in identifying and prioritising core areas and important biodiversity “hot spots”. Refer to above section [Characteristics of a Resilient Ecological Network \(REN\)](#) for more details.

Understanding place and the role of history and cultures

Historic environment features have been identified by the four Welsh Archaeological Trusts on behalf of Cadw. They are features and landscapes that retain a physical presence but they are not always protected by a statutory designation.

Socio-economic data will also provide information about local cultural characteristics and sensitivities.

Understanding place and the role of ecosystems services

Finally, consider the suite of ecosystem services that nature provides to society within the landscape. Ecosystems provide a host of services and goods: fibre, food, fuel, climate regulation, erosion control, flood regulation, disease and pest control, noise regulation, recreation and tourism, aesthetic values, cultural heritage, education, employment, genetic material, spiritual values, fresh air and water (see Figure 4 (UK NEA, 2011)).

A place-based assessment of ecosystem services provides understanding of the current and potential benefits provided by ecosystem services in an area and how they relate to people at different spatial scales.

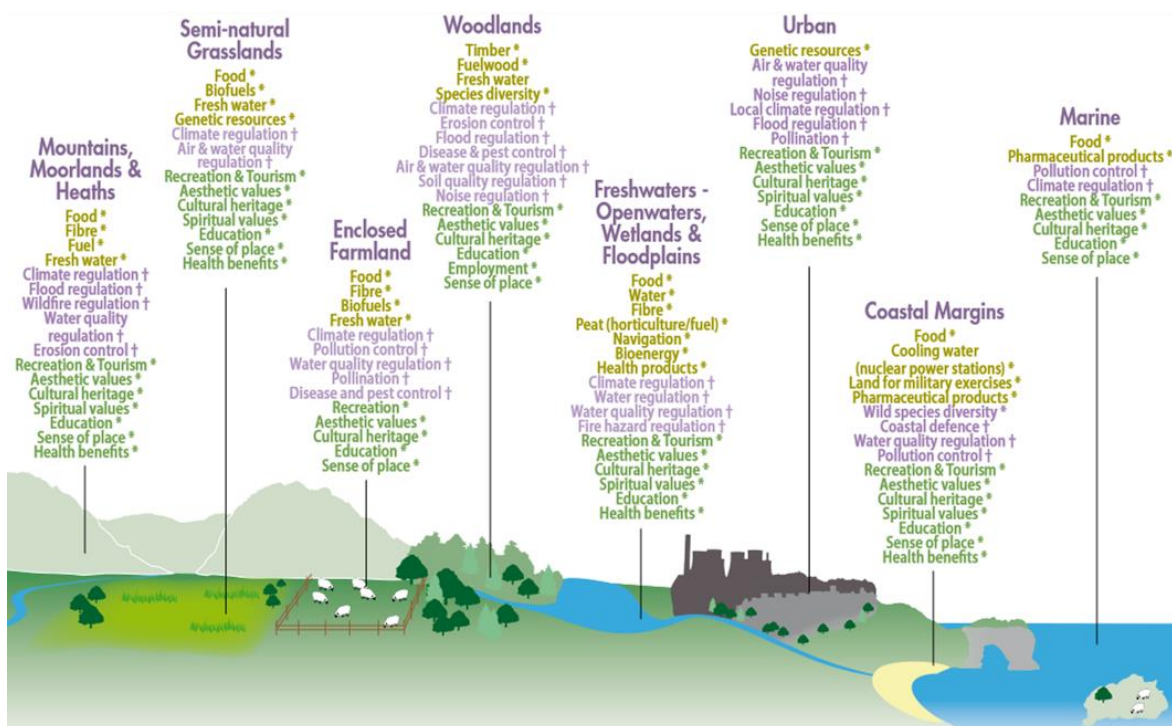


Figure 4: List of ecosystems services provided by the eight main ecosystems

Step 2 Create a vision

Key task: Agree the vision statement

An overview in words, images and maps describing current states and how this landscape could appear with improved levels of resilience for biodiversity, and ecosystems services.

Key task: Share and build agreement for the guiding principles, rules of thumb and the direction of travel

Guiding principles are to work in partnership using the SMNR approach to find nature-based solutions (where possible) and:

- Identify the spatial scale
- Maintain and enhance ecological resilience and biodiversity
- Identify the environmental pressures and drivers for change
- Use the evidence collated in Step 1 to model and design the interventions using the suite of ecological “rules of thumb” to set the correct direction of travel (Figure 4).
- Identify ecosystem services, goods and benefits that would also arise from actions.
- Design feedback loops for adaptive management
- Select indicators that lend themselves to monitoring and surveillance

Key task: Build the vision using networks, embracing dynamism and encouraging diversity

Use participatory approaches [to engage with stakeholders](#) and present data using a variety of tools to further build a common vision. Find methods to resolve potentially conflicting priorities and acknowledge constraints while designing the plan. Work together to identify short, medium, and long-term landscape scale objectives and specific, measurable, achievable, realistic and time-bound (SMART) targets (HM Treasury, 2003) for;

- Ecosystem restoration, habitat creation and restoring natural processes
- New and enhanced ecosystem service provision

Key task: Start building the plan

Choose a format suited to the community’s purpose.

Key task: Public engagement

Identify the most appropriate ways to build support, understanding and gain feedback from the public for the vision and plan. Find a popular and consistent vocabulary.

Key task: Prepare the final vision and plan

Refine the plan which should have well-defined issues, transparent judgement values for setting priorities, a risk register and include details of how to monitor the SMART targets and respond to any slippages. Indicators and goals will be required for:

- Biodiversity and ecosystem resilience
- Ecosystem services
- Landscape character and cultural heritage
- Societal demands, for example, access to the countryside, education and research.

Having reviewed the place and considered the ecological aspects of REN development, a holistic plan that integrates the needs of nature, natural processes, geodiversity, people and landscape needs to be developed. This should be underpinned by a vision that outlines overall direction for a landscape, created through participatory engagement and

discussion with key stakeholders. Connections with the objectives of the relevant Area Statement should also be explicit.

Modelling tools for understanding ecological networks

A range of existing datasets and geo-spatial tools are available to help practitioners develop RENs and it is inevitable that the range of resources will increase as the concepts of ecological networks and ecosystem resilience becomes more widely adopted.

Natural Resources Wales has published a series of Habitat Network maps which describe the current state of ecological connectivity between semi-natural habitat patches across Wales. These maps identify important existing areas of connectivity for ecosystem resilience so that they can be considered within spatial planning. The maps are accompanied by a practitioner's guide to why and how the maps were created and is illustrated with 'real world' worked examples (Latham and Rothwell, 2019). Practitioners can currently access, apply and interpret habitat maps for:

- broadleaved woodland
- semi-natural grassland
- heathland
- fen
- bog

The modelling will need to show overlap between different habitat types and so it is advised not to look at single habitat maps when planning a strategy. It is envisaged that additional maps for additional habitats, for example, hedgerows, will be created in the near future.

The more detailed "Level 2" Habitat Networks provide a good starting point to begin development of RENs because they describe the current state of connectivity between protected sites. They can be considered as arteries within Resilient Ecological Networks and other data can be considered and utilised to refine and extend these arteries and create finer capillary networks. Further details in [Appendix 2](#) (Latham and Rothwell, 2019).

Other mapping tools exist but these usually relate to single habitat types or they require higher level technical skills which may not be available to every partnership looking to develop RENs.

A list of ecological rules of thumb

The State of Natural Resources reports from 2016 and 2020 (NRW, 2016; 2020a) state that ecosystems in Wales are unlikely to have enough resilience to cope with expected and unforeseen change arising from pressures and demands such as climate change. This indicates that there are significant problems which are very likely to effect the capacity of habitats and species to continue to function and sustain ecosystem services. This can be addressed by land-use strategies that help to build ecosystems that are more resilient to environmental shocks and which should be buffered from external pressures and demands but can still provide ecosystem services. Integral to these strategies is the understanding that we must provide the most comprehensive and resilient outcomes for biodiversity.

Actions that build the condition and diversity of existing ecosystems, and maintain or restore their extent, and structural / functional connectivity are required. Here, we build upon these principles to provide further 'how to' advice.

Natural England reviewed the scientific literature to identify ecological “rules of thumb” to help practitioners design networks (Crick *et al*, 2020a; 2020b). Their aim was to help prioritise the aspects identified by Lawton *et al.* (2010) and to provide some definition to the questions of how to make sites better, how big should they be, how and where more sites should be placed, and the best ways to improve connectivity. The rules were backed up with a detailed evidence review for each so that practitioners could understand their origin and applicability. The rules can be applied at different scales and are expected to improve long-term habitat quality, maintain and enhance species, improve or reinstate beneficial natural processes, and in some cases reduce the risk of pollution occurring.

This list of desirable rules has been adapted to the Welsh policy context by relating them to the DECCA framework for ecosystem resilience (Figure 1) and here they have been grouped under their main resilience attribute. In reality the actions will often build more than one attribute and ideally the programme of actions should be designed to improve multiple ones.

When applying these rules of thumb to the design of Resilient Ecological Networks, it is important to take account of existing ecosystem resilience attributes in deciding ecological priorities. Central to the development of a REN is the inclusion of protected sites as core areas which act as biodiversity reservoirs that brim over into the rest of the network and secure important ecosystem services. Priority should be given to maintaining and restoring biodiversity and ecosystem functionality within protected sites. In addition, not all types of rules and actions apply to all habitats and not all rules will necessarily be applicable in all circumstances. Identifying an appropriate set of priorities and actions should be decided based on the local environmental context and using relevant expert advice.

The ecological “rules of thumb” are:

Diversity - greater variety of habitats and species

- Maintain rare species
- Restore missing biodiversity by increasing niches or translocating species in accordance with the International Union for Conservation of Nature (IUCN, 2013) and NRW advice and guidance
- Target areas of important habitat potential in the intervening land-use matrix
- Target areas of unprotected high value habitat or habitat with a long ecological history of non-intensive land management
- Target areas with complex or additional topography and geomorphology and with a potential to be climate change refugia
- Target degraded semi-natural habitat areas with potential to restore multiple ecosystem service delivery using Nature-based solutions, for example, prevention of soil erosion and flood risk, carbon capture

Extent – supporting the optimum size of habitat and its capacity to support populations of species

- Add larger sites in preference to several smaller sites, depending on the spatial arrangement and habitat types between them

- Enlarge sites as a precautionary approach although the scale of enlargement will depend on the type of habitat and the ecology of the species present³
- Provide space for ecosystem dynamism, supporting mosaics and to encourage succession
- Reduce edge effects by decreasing the edge to area ratio where there is sufficient extent of habitat
- RENs should be large enough to enable native species to move to suitable habitat in response to climate change
- RENs should be large enough to encourage natural processes and ensure functioning ecosystems
- Restore degraded habitats surrounding the core areas. Use a strategic approach and the NRW Habitat Network mapping tool (Appendix 2)

Condition – improving and maintaining habitat quality and population abundance

- Consider variation in physical structure (messiness); this consideration is likely to be more appropriate in extensive, rather than small isolated semi-natural habitats.
- Create more niches for more species – use ‘ecosystem engineers’ and welcome ecological disturbance
- Create softer and protective transition zones between core areas and the wider countryside with at least a 50 - 100 metre buffer strip, possibly up to 500 metre wide depending on the types of pressures and demands
- Encourage habitat mosaics
- Encourage natural processes
- Manage semi-natural habitats to protect soil health, for example, low inputs for grassland management or the retention of ancient semi-natural woodland
- Positively maintain core areas (components include statutory and non-statutory sites and priority habitats) to maintain and/ or restore biodiversity and functional processes
- Reduce edge effects by buffering sites and encouraging graded transitional habitat to ‘soften the edge’

Connectivity – physical and functional links between and within habitats supporting the capacity for species and environmental resources to move across the landscape

- Ensure connectivity is good for new sites
- Ensure connective habitat matches or are complementary to that in core areas
- Expand sites towards existing habitat to reduce space between patches. Use a strategic approach and the NRW Habitat Network mapping tool
- Maintain and restore natural transitions between coastal, freshwater and terrestrial habitats
- Maintain or create connective areas of land (corridors) to facilitate the movement of species. Corridors could be designed with specific species in mind, but a corridor of at least 100 metres wide is likely to be a minimum width requirement
- Natural corridors are better than human designed corridors
- Reduce the intensity and increase the diversity of land-use in the surrounding countryside

³ Further research and modelling is required to understand the relationship between size thresholds and the amount of biodiversity gain for different habitats.

- Stepping stones should provide appropriate resources to avoid becoming ecological traps
- There is a gap crossing threshold for some species so frequent stepping stones of habitat are beneficial. Gap size may require additional research specific to a habitat or species, for example, for poorly dispersing species such as amphibians and snakes, sites should be less than 1 kilometre from each other, and less than 200 metres apart for highly specialised species within a habitat, for example, woodland plants.
- Use linear landscape features

In addition, there is a list of useful conservation actions that practitioners may wish to use in freshwater habitats listed in Appendix 3.

Travelling in the right direction to maintain or restore a resilient ecosystem

The recovery time for a damaged ecosystem varies and often it may not achieve previous levels of resilience for years or even decades after the corrective management regime has been established, so guidance for the correct direction of travel helps to prioritise action.

Figure 5 (adapted from Crick *et al*, 2020a) shows the direction of travel required for each resilience attribute to maintain or restore ecosystem functioning and improve resilience. As an example, an ecosystem with very few species that support a functioning system would need to move along a continuum towards a state where the full range of species necessary to a healthy ecosystem are present. To achieve this outcome the management actions would be aimed at improving diversity.

Whenever possible, the main principle should be to work with natural processes and give them enough space to operate. This requires consideration of hydrology, nutrients, soil and sediment processes, and factors that control vegetation growth and species composition. Consideration should also be given to integrating objectives for biodiversity (Mainstone *et al*. 2018). Where a project location includes designated sites then these areas should form the core of the plan and the fundamental first step should be to improve their condition by maintaining or restoring natural ecosystem functionality.

In addition, the practitioners should be mindful that climate change refugia should form key parts of ecological networks as they are likely to improve resilience for species within landscapes. Rare, long-distance dispersal events are also likely to be important for many species, so receptor site quality and quantity is therefore very important.

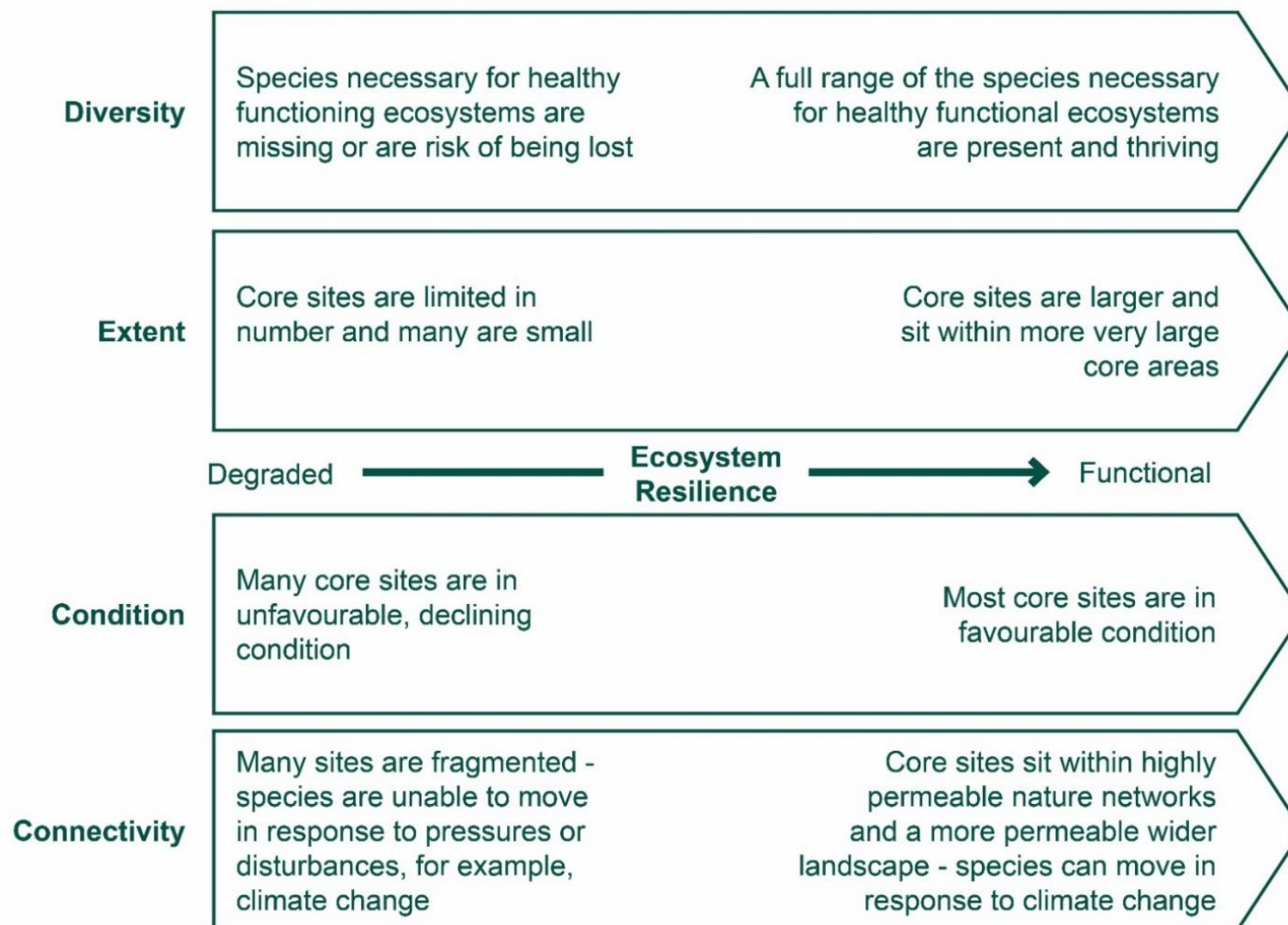


Figure 5: The ecological direction of travel for improving ecosystem resilience

Step 3 Developing and implementing the REN - start now but think long term

Key task: Check for compliance risks

Understand what legislative requirements may apply to implementation of the plan including what environmental and development planning permissions, permits and licenses may be needed and the process and timescales for acquiring these. Ensure appropriate permissions, permits and consents are in place prior to delivery.

Apply voluntary and good practice standards, for example, the [UK Forestry Standard](#) (UKFS) (Forestry Commission, 2017) and agricultural minimum standards to relevant parts of the plan delivery.

Key task: Form a delivery team

What skill sets are required? What sources / levels of funding are required and available? What are the risks to the project?

1. Explore what governance options exist to manage delivery, examples include formation of a delivery partnership of existing stakeholders governed by a Memorandum of Understanding or the creation of a new organisation with a specific remit to deliver the plan. Consider the advantages and disadvantages of each option.
2. Identify leads (teams) for each key aspect of the project
3. Leads to develop action plans to take forward their elements of the Plan.
4. Project teams work together to ensure an overall integrated plan
5. Implement plans - start immediately but think long-term.

Set up an adaptive management plan cycle with reviews at pre-determined intervals. The review period should be in-step with monitoring and reporting cycles.

Key task: Implement and monitor the plan

Project and programme management templates to establish risks, milestones, time scale and financial control are often available on websites and are free to download.

How RENs might further develop in the future

This practitioners' guide is intended to do the preparatory groundwork for people intending to implement policies or sustain open-ended activities that improve ecosystem resilience using the concept of Resilient Ecological Networks as a core vehicle for intervention.

The environmental challenges that we face in Wales are not unique and like other countries we are creating tools and strategies that will assist everyone in responding appropriately to the nature and climate emergencies and to help us live within our planetary boundary. Appropriate behaviour changes will need to be supported and there is a suite of potential mechanisms; for example, the IUCN has recently developed a [Global Standard for Nature-based Solutions](#) (Nb-S) for use by governments, businesses, investors, communities and NGOs to ensure that nature based solutions are correctly applied and fulfill their possibilities (Cohen-Schaham, *et al*, 2016).

There may also be the potential to create a similar voluntary national standard for the ecological networks approach to build best practice and develop a common language and understanding. The standard might include habitat restoration, species recovery and net gain targets, management agreement mechanisms and governance arrangements to secure their longevity and benefits for future generations. Progress could be assessed using monitoring or surveillance data for a range of environmental, ecological, economic and social benefits, such as carbon capture, flood management, clean water, pollination and recreation.

To move from policy into practice there is a pressing need to delineate, develop and deliver RENs and fundamental to this is the establishment of related, effective, long-term governance. Using a voluntary standard, an intervention could be self-assessed against a small number of REN criteria and indicators to act as a quality hallmark to demonstrate to funders and potential partners how the concept of REN has been understood and applied. Such sustainable land management projects could go even further and through quality assurance schemes attract financial support from businesses and individuals looking for green and ethical investment opportunities. These ideas require more exploration, but they are mentioned here as fodder for thought and further discussion.

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Appendix 1 Checklists

Checklists associated with the decision support framework

Checklist 1: Important legislation and policy documents

Checklist 2: Evidence to describe place

Checklist 3: Strategies and plans

Checklist 4: Environmental standards and good practice

Checklist 5: Guidance on stakeholder and public engagement

Checklist 6: List of pressures and drivers for environmental change

Checklist 7: Ecosystems services

Checklist 1: Important legislation and national policy documents

The following is a list of key documents, but it is not intended to be exhaustive.

There will be other additional important documents relating to different sectors in Wales.

Welsh Government publications:

- Act, Agriculture (Wales) publication pending
- [Act, Environment \(Wales\) 2016](#)
- [Act, The Planning \(Wales\) 2016](#)
- [Act, Well-being of Future Generations 2015](#)
- [Plan, National Development Framework draft](#) (Final published title will be: Future Wales – The National Plan 2040)
- [Policy, Natural Resources](#)
- [Plan, Nature Recovery Action 2020](#)
- [Policy, Planning Wales](#)

Natural Resources Wales publications:

- [Environmental Impact assessment](#)
- [Permits and permissions](#)
- [Protected species licensing](#)

Wales Biodiversity Partnership publications:

- [Priority species and habitats](#)

Checklist 2: Evidence to describe place

Type of data available from the [Consumer Data Research Centre](#) and [Data Shine Census](#)

- Socio-economic

Type of data available from the [Historic Wales information portal](#) and [Coflein](#)

- Cultural and historic

Information available from local authority websites

- Non-statutory sites

Experimental research data available from [Living Wales portal](#)

- Biological data inc. species
- Environmental condition
- Environmental risk
- Habitats
- Land-use
- Physical data

Type of data available from the Welsh Government [Lle data and information hub for Wales](#):

- Access and recreation
- Biological data inc. species
- Cultural and historic
- Environmental condition
- Environmental risk
- Ecosystems services
- Habitats
- Landscapes
- Land-use
- Physical data
- Shoreline Management Plan maps
- Socio-economic

Note that in 2021 the Lle portal will be replaced with Data Maps Wales (DMW) portal. [This link to the DMW test site was available](#) at the time of publication.

Types of data available from [local biological records centres](#)

- Biological records and some data analysis for species and habitats
- Biological data gap analysis

Information available from [Natural Resources Wales \(NRW\) website](#)

- Access and recreation
- Habitats
- Landscapes
- Statutory sites i.e. SSSI, SAC, SPA, Ramsar etc.
- National Landscape Character Areas (NLCA) and guidance on LANDMAP
- Area Statement priorities and themes
- Protected species licenses

Information available from Natural Resources Wales protected sites database.

This stakeholder portal will allow NRW's partners to access information on designated sites. The portal is currently under development [March 2021] but information relating to levels of access and data licensing processes will be published in 2021. Please check the NRW website for further information.

Type of data available from the NRW [Wales Environmental Information portal](#)

- Access and recreation
- Biological data inc. species
- Cultural and historic
- Environmental condition
- Environmental risk
- Ecosystems services
- Habitats
- Landscapes
- Land-use
- Physical data
- Statutory sites, i.e. SSSI, SAC, SPA, Ramsar etc.

Types of data available from the [UK Soil Observatory portal](#)

- Biological data inc. species
- Environmental condition
- Environmental risk
- Habitats
- Land-use
- Physical data

Checklist 3: Area based and thematic strategies and plans

Major plans and strategies published by [Natural Resources Wales including:](#)

- Area Statements
- Catchment Abstraction Management Plans
- Flood Risk Management Plans
- Forest Resource Plans
- Grant funding strategies
- Natura 2000 Protected Sites Thematic Action Plans
- River Basin Management Plans
- Shoreline Management Plan policy
- SSSI site management statements

Major plans and strategies published by local authorities and Public Service Boards including:

- Local biodiversity action plans (historic)
- Local development plans
- Rights of Way Improvement plans
- National Park management plans (where appropriate)
- AONB management plans (where appropriate)
- Well-being plans
- Green Infrastructure assessments

Checklist 4: Environmental standards and good practice

Sector guidance, standards and good practice may change as Wales transitions to new trading agreements and schemes following the UK exit from the European union. This checklist provides a few web links, but the practitioner is encouraged to research the latest developments.

Advice published by CADW

- [Historic assets guidance](#)

Advice published by Forest Research:

- [UK Forestry Standard](#)

Advice published by Natural Resources Wales

- [Acid sensitive catchments](#)
- [Agricultural good practice](#)
- [Environmental Impact assessment](#)
- [Forestry resilience](#)
- [Permits and permissions](#)
- [Recreation and access codes](#)
- [Sector based guidance and advice](#)

Advice published by Welsh Government

- [Development planning guidance and advice](#)
- [Forestry guidance and advice](#)
- [Land management guidance and advice](#)
- [Wildlife and habitat conservation guidance and advice](#)

Be aware that other UK public sector organisations also publish guidance which may apply, or be applicable, to Wales, for example, DEFRA. In addition voluntary organisations and academic institutes may also recommend best practice or summarise the research into the effectiveness of interventions, for example, [Building with Nature Standards](#), and [Conservation Evidence](#).

Checklist 5: Guidance on stakeholder and public engagement

Resources are available from [Wales Biodiversity Partnership](#) and [Local Nature Partnerships](#) in Wales. The relevant [NRW Area Statement](#) may also be able to provide insights into local stakeholder concerns and priorities.

Many voluntary sector organisations have published toolkits and guidance. It's recommended that an internet search for your sector or locality could yield useful resources and advice, for example, [community planning toolkit](#).

Checklist 6: List of pressures and drivers for environmental change

Publications by Natural Resources Wales:

- [State of Natural Resources Report 2020](#) chapters [include natural resource risk assessments](#) and ecosystem chapters discuss the main drivers and pressures for environmental decline (NRW, 2020a).
- [Area Statements](#) include locally prioritised themed actions (NRW, 2020c).
- Current Relative Ecosystem Resilience (CuRVE) maps show patterns of relative resilience resolved at a scale of one-kilometre square (Naumann and Medcalf, 2019).

Checklist 7: Ecosystems Services

Publications by Natural Resources Wales:

- [State of Natural Resources Report 2020](#) – see chapters on natural resources stocks and registers, the summary chapter and relevant individual ecosystem themed chapters (NRW, 2020a)
- [Area Statements](#) (NRW, 2020c).

Publications by joint agencies:

- The [UK National Ecosystem Assessment was published in 2011](#) (Scowen *et al*) and it is the first analysis of the UK's natural environment in terms of the benefits it provides to society and continuing economic prosperity. It is a useful reference source as the figure below demonstrates.

Appendix 2 Habitat Network maps

Habitat Network maps are a resource for understanding functional and structural connectivity

Natural Resources Wales has published a series of habitat network maps which describe the current state of ecological connectivity between semi-natural habitat patches across Wales. Connectivity is an important attribute of ecosystem resilience because it is a major driver of spatial variation which affects diversity and bioabundance. The Habitat Network maps are a key resource for understanding and informing interventions to improve ecological connectivity, and to help build ecosystem resilience. Maps have been already been produced for:

- broadleaved woodland
- semi-natural grassland
- heathlands
- fens
- bogs

The maps were created using a well-established model that considers land cover type, and the habitat area requirements and dispersal abilities of the habitats' typical species. The networks do not represent particular species, but use values selected to represent a broad range of biodiversity.

Three sorts of networks have been mapped to represent the requirements of a wide spectrum of species. These are:

- core networks, for species that require a lot of their habitat and disperse poorly;
- focal networks for species that require less habitat and disperse reasonably well; and
- local networks for species that require only small areas of habitat and disperse very poorly.

Together, these networks cover many of the characteristics of typical species that are likely to benefit from networks and give an indication of the range of variation of networks for their home habitat as a guide to overall ecological connectivity.

A further iteration of these maps, known as Level 2, have been created to show biodiversity "hotspots" and key areas for improving connectivity where Sites of Special Scientific Interest (SSSI) form the core of a network.

What the habitat network maps demonstrate

The basic outputs of the model are 'buffers' around habitat patches that relate to the area within which typical species of that habitat are likely to be able to move. They are not uniform buffers however and vary in width depending on how favourable for movement the surrounding land is likely to be. Where buffers overlap, the habitat patches within them are *functionally connected*, meaning that many typical species will be able to move between them. These habitat patches, together with the buffers that surround them and other habitats they contain are referred to as a *habitat network*. The perceived ease of

movement through different habitats is known as *permeability*, and this is quantified in the model in terms of 'ecological cost'.

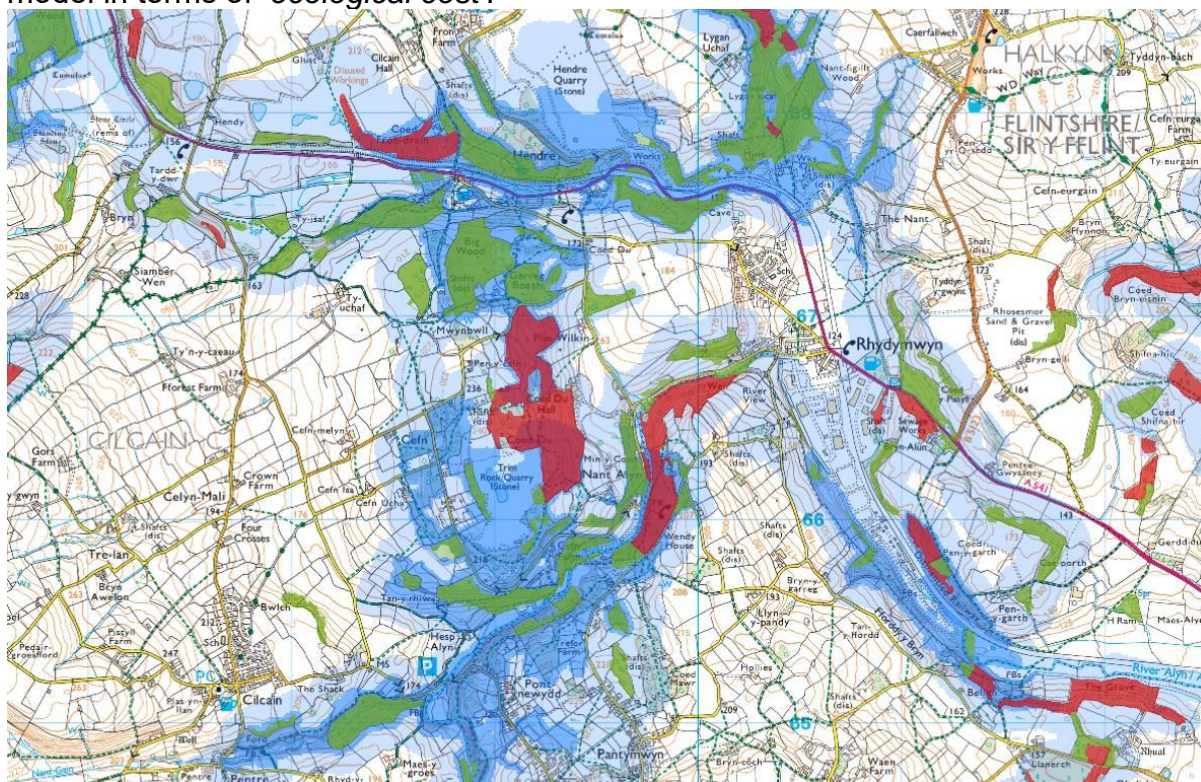


Figure 6. Broadleaved woodland habitat networks

In figure 5 broadleaved woodland is shown in green, core networks are shown in dark blue, focal networks in light blue; Planted Ancient Woodland Sites (PAWS) in red. This example illustrates how the networks can help to prioritise restoration of PAWS woodland to improve broadleaved woodland networks and hence connectivity within a landscape. (In practice the decisions for woodland creation would also be balanced against the potential of other priority habitats).

In addition, networks that contain protected sites or other high-quality biodiversity hotspots have been identified and are called Priority habitat networks.

Key applications for the Habitat Network maps

Key applications of the network maps, working in conjunction with other datasets, are to:

- Provide a general understanding of ecological connectivity within landscapes to inform Sustainable Management of Natural Resources (SMNR).
- Guide the location of habitat restoration, creation and management to improve ecological connectivity and ecosystem resilience.
- Provide an understanding of the ecosystem value of any habitat patch in Wales, for example to help inform planning decisions and mitigation.
- Identify functional units for biodiversity within landscapes to promote and help apply coordinated management.
- Explore opportunities for developing multiple benefits across ecosystem services.
- Develop *Resilient Ecological Networks* that support robust and functional series of biodiversity hotspots whilst contributing resilience and ecosystem services to the wider environment.

How not to use the habitat network maps

The networks can also be misused. A common misconception is that they are prescriptive, showing areas that 'should' be converted to a particular habitat, for example that a heathland network defines areas that should be entirely converted to heathland. This is wrong and misunderstands the concept of a functional network in which connectivity is provided not just the habitat of interest, but also other habitats that are to some degree permeable to species movement. Networks are modelled predictions of *current* connectivity, that with careful interpretation can inform future management or land-use decisions.

Where to find the maps and guidance

Habitat Network maps are available on the WG Lle data portal, and the accompanying technical guide is available as an NRW reports from the NRW library service (Latham and Rothwell, 2019). An additional earlier report exploring connectivity may provide useful guidance (Latham *et al*, 2013)

Appendix 3 Conservation actions for freshwater habitats

The column on the left indicates various freshwater actions related to improving resilience. These are all actions that can be expected to improve long-term habitat quality, improve or reinstate beneficial natural processes, or reduce the risk of pollution occurring. The resilience benefits for each attribute of resilience are rated as good or very good for diversity, extent, condition and connectivity. Not all intervention types apply in all freshwater habitat types so the environmental relevance of each action is indicated for headwaters, larger rivers and floodplains, lakes and ponds. Not all actions will necessarily be applicable in all circumstances and identifying an appropriate set of actions should be carried out based on the local environmental context and using relevant expert advice.

Actions to improve resilience	Diversity	Extent	Condition	Connectivity	Headwaters	Larger rivers and floodplains	Lakes	Ponds
Restore headwater wetlands and streams	Good	Good	Good	Good	Relevant		Relevant	Relevant
Block man-made drains and ditches		Good	Very good		Relevant	Relevant	Relevant	Relevant
Reconnect rivers to their floodplains	Very good	Good	Very good	Good		Relevant		Relevant
Allow natural levels of bank erosion	Good	Good	Good	Good	Relevant	Relevant		
Remove or set back hard flood defences and bank protection	Good	Good	Good	Very good	Relevant	Relevant		
Protect and restore riparian corridor vegetation to provide habitat, shade and bank stability.	Good		Very good	Good	Relevant	Relevant	Relevant	

Actions to improve resilience	Diversity	Extent	Condition	Connectivity	Headwaters	Larger rivers and floodplains	Lakes	Ponds
Encourage development and maintenance of riparian wetlands, woodland, backwaters and oxbow lakes	Very good	Good	Very good	Good	Relevant	Relevant	Relevant	Relevant
Increase instream physical habitat diversity, such as reinstating or protecting boulders and introducing large woody debris	Very good		Very good		Relevant	Relevant		
Remove dams, weirs and culverts	Good		Good	Very good	Relevant	Relevant		
Restore semi-natural floodplain and wetland habitats.	Very good	Good	Very good	Very good	Relevant	Relevant	Relevant	Relevant
Allow channels to move freely across floodplain, providing space for ecosystem dynamism, supporting mosaics and encouraging succession	Good	Very good	Very good	Good		Relevant		Relevant
Create new wildlife ponds and pond networks	Good	Very good	Good	Good				Relevant
Reduce the intensity of land-use in the surrounding countryside	Good		Very good	Good	Relevant	Relevant	Relevant	Relevant
Create and maintain landscape features that intercept pollution, such as swales, constructed wetlands, buffer strips, and sediment trap ponds	Good		Very good	Good	Relevant	Relevant	Relevant	Relevant
Manage grazing levels in the riparian zone	Good		Very good	Good	Relevant	Relevant	Relevant	Relevant

Actions to improve resilience	Diversity	Extent	Condition	Connectivity	Headwaters	Larger rivers and floodplains	Lakes	Ponds
Target lowland and areas with alkaline geology for restoration measures, as these have been most heavily impacted by agricultural intensification and support higher diversity	Very good	Good	Very good	Good	Relevant	Relevant	Relevant	Relevant
Target areas of important habitat potential in the surrounding area	Good	Good	Good	Good	Relevant	Relevant	Relevant	Relevant
Utilise watercourses as natural dispersal corridors	Good		Good	Very good	Relevant	Relevant		
De-silt / coppice around ponds on a rotational basis	Very good	Good	Very good	Good				Relevant
Maintain rare species	Good		Good	Good	Relevant	Relevant	Relevant	Relevant
Restore missing biodiversity by increasing niches or by reintroduction, especially for ecosystem engineer species such as freshwater pearl mussel	Very good		Very good		Relevant	Relevant	Relevant	Relevant
Encourage natural ecological disturbance and succession	Very good	Good	Very good	Good	Relevant	Relevant		Relevant
Prevent spread of Invasive Non-Native Species	Good		Very good		Relevant	Relevant	Relevant	Relevant
Manage coarse fish and waterfowl populations	Good		Very good				Relevant	Relevant
Restore peatlands, including ditch blocking	Good	Good	Very good		Relevant	Relevant	Relevant	Relevant
Work at catchment or sub-catchment scale			Good	Good	Relevant	Relevant	Relevant	Relevant

Appendix 4 Data Archive

No data outputs were produced as part of this project.