The Second State of Natural Resources Report (SoNaRR2020)

Assessment of the Achievement of SMNR Aim 2: Ecosystems are Resilient to Expected and Unforeseen Change.

Natural Resources Wales

Final Report

Mae'r ddogfen hon hefyd ar gael yn Gymraeg

About Natural Resources Wales

Natural Resources Wales's purpose is to pursue sustainable management of natural resources. This means looking after air, land, water, wildlife, plants and soil to improve Wales's well-being, and provide a better future for everyone.

Evidence at Natural Resources Wales

Natural Resources Wales is an evidence-informed organisation. We seek to ensure that our strategy, decisions, operations and advice to Welsh Government and others are underpinned by sound and quality-assured evidence. We recognise that it is critically important to have a good understanding of our changing environment.

We will realise this vision by:

- Maintaining and developing the technical specialist skills of our staff;
- Securing our data and information;
- Having a well resourced proactive programme of evidence work;
- Continuing to review and add to our evidence to ensure it is fit for the challenges facing us; and
- Communicating our evidence in an open and transparent way.

Title: **SoNaRR2020 Aim 2: Ecosystems are Resilient to Expected and Unforeseen Change**

Lead Author: **H Garrett**

Contributors: **S Ayling, J Latham, S Smith, J Creer, H Lewis, D Crook, M Meaden, C Tucker, N Taylor, C Burrows, N Menichino, R McCall, M Lewis, R De'Ath**

Peer Reviews: Internal and external peer review

Restrictions: None

Amendments:

Document version	Amendment
Version 2.0	Figure 11 amended to include additional categorisations
Version 2.1	Small change on page 16

The Second State of Natural Resources Report (SoNaRR2020) contents

This document is one of a group of products that make up the second State of Natural Resources Report (SoNaRR2020). The full suite of products are:

Executive Summary. Foreword, Introduction, Summary and Conclusions. Published as a series of webpages in December 2020

The Natural Resource Registers. Drivers, Pressures, Impacts and Opportunities for Action for eight Broad Ecosystems. Published as a series of PDF documents and as an interactive infographic in December 2020

Assessments against the four Aims of SMNR. Published as a series of PDF documents in December 2020:

SoNaRR2020 Aim 1. Stocks of Natural Resources are Safeguarded and Enhanced

SoNaRR2020 Aim 2. Ecosystems are Resilient to Expected and Unforeseen Change

SoNaRR2020 Aim 3. Wales has Healthy Places for People, Protected from Environmental Risks

SoNaRR2020 Aim 4. Contributing to a Regenerative Economy, Achieving Sustainable Levels of Production and Consumption

The SoNaRR2020 Assessment of Biodiversity. Published in March 2021

Assessments by Broad Ecosystem. Published as a series of PDF documents in March 2021:

Assessment of the Achievement of SMNR: Coastal Margins

Assessment of the Achievement of SMNR: Enclosed Farmland

Assessment of the Achievement of SMNR: Freshwater

Assessment of the Achievement of SMNR: Marine

Assessment of the Achievement of SMNR: Mountains, Moorlands and Heaths

Assessment of the Achievement of SMNR: Woodlands

Assessment of the Achievement of SMNR: Urban

Assessment of the Achievement of SMNR: Semi-Natural Grassland

Assessments by Cross-cutting theme. Published as a series of PDF documents in March 2021:

Assessment of the Achievement of SMNR: Air Quality

Assessment of the Achievement of SMNR: Climate Change

Assessment of the Achievement of SMNR: Energy Efficiency

Assessment of the Achievement of SMNR: Invasive Non-native Species

Assessment of the Achievement of SMNR: Land use and Soils

Assessment of the Achievement of SMNR: Waste

Assessment of the Achievement of SMNR: Water Efficiency

Updated SoNaRR evidence needs. Published in March 2021

Acronyms and Glossary of terms. Published in December 2020 and updated in March 2021

Recommended citation for this section of the report:

Natural Resources Wales. 2020. State of Natural Resources Report (SoNaRR): Assessment of the Achievement of SMNR Aim 2: Ecosystems are Resilient to Expected and Unforeseen Change. Natural Resources Wales.

Copyrights

Introduction to the four aims of SMNR

SoNaRR2020 assesses Wales's progress towards SMNR individually against four aims of SMNR, but it is important to note that they are inextricably linked and should not be seen in isolation (Figure 1). Wales cannot work towards healthy places for people without resilient ecosystems and cannot make our ecosystems resilient without safeguarding stocks of natural resources. The regenerative economy safeguards and restores those stocks and is the route to the transformational change needed to achieve SMNR.

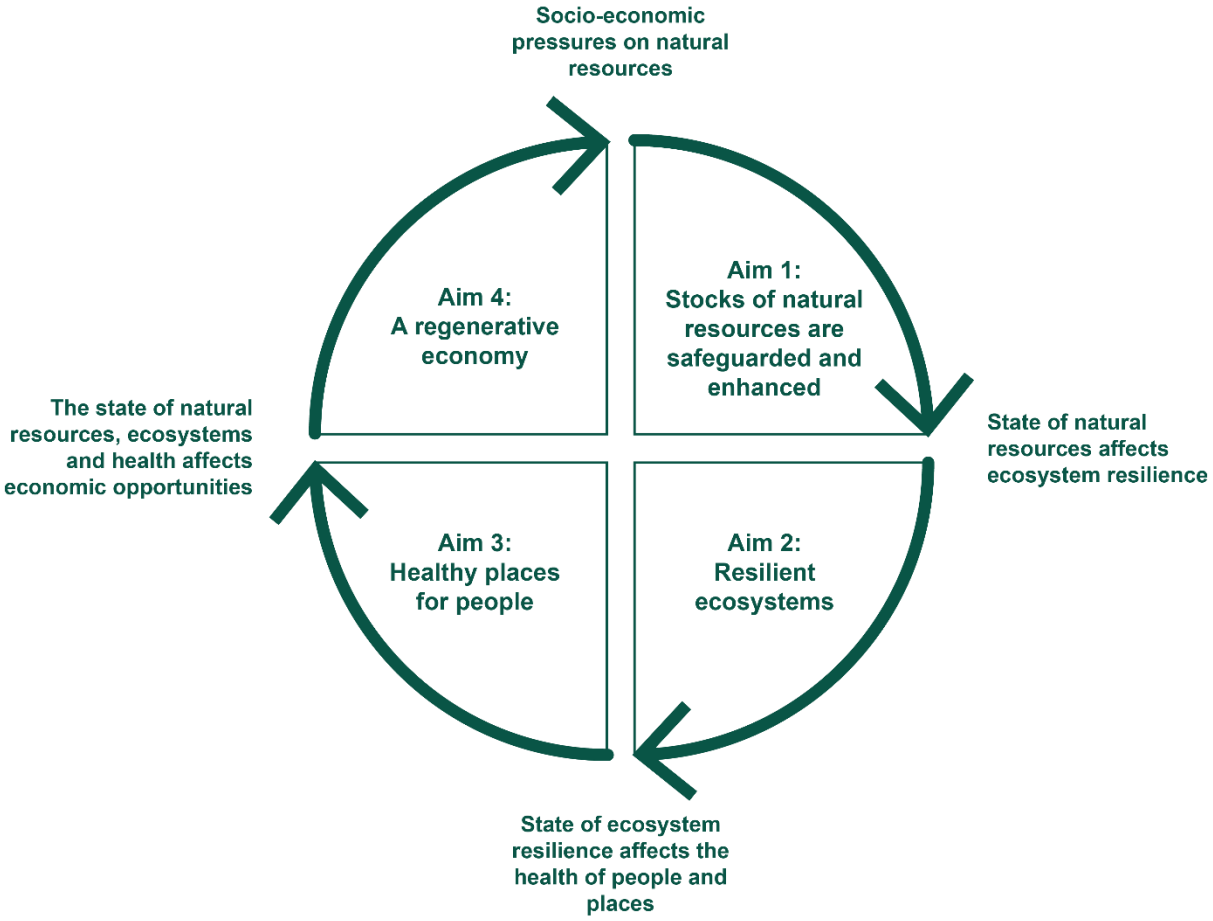

Figure 1 The linkages and cyclical nature of the four aims of SMNR.

SMNR Aim 2: Ecosystems are resilient to expected and unforeseen change

Success would see healthy, functioning ecosystems that are able to safeguard and maintain supporting ecosystem services and their benefits. Ecosystem resilience 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 (Walker and Salt, 2012).

Here those disturbances include (but are not limited to):

- habitat loss and deterioration
- climate change
- pollution
- invasive non-native species

Contents

Tables and Figures

Summary: Ensuring ecosystems are resilient

Human existence and well-being are threatened by ecological and environmental breakdown. The consequences of an inadequate response to these threats would be catastrophic for Wales and the world. The capacity to understand and build resilient ecosystems should form the mainstay of an effective response.

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 able to deliver goods, services and benefits into the future. Resilience could be significantly improved by adopting a sustainable management strategy for life across land, freshwater and seas. There are regulatory and policy frameworks in place, but we as a society need to act faster, more joined up, at a better and larger spatial scale. There is a need to build on the increasing public awareness of the unhealthy state of natural resources in Wales, to win support for a significant step-change in behaviours (Steentjes et al., 2020).

Opportunities identified for action are:

- Develop the assessment of ecosystem resilience
- Build on Wales's policy framework
- Optimising regulation
- Effective ecosystem management
- Build wider engagement

Introduction: What is ecosystem resilience?

This chapter focuses on why ecosystem resilience is important, and how it can be assessed. Under the Environment (Wales) Act, Natural Resources Wales and other bodies should seek to maintain and enhance biodiversity and the resilience of ecosystems. To this end we have developed a conceptual resilience framework for Wales, and new tools to put it into practice. Resilience is core to the new, integrated approach to the environment, which is based on the flow from ecosystems, through ecosystem services and benefits, to well-being. Sustainable Management of Natural Resources (SMNR), is the means by which the Welsh environment is managed to achieve this flow, and resilience is the property of ecosystems that allows the flow to persist in the face of impacts and change.

This assessment is based on the definition of Ecosystem resilience from SoNaRR2016, 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".

Ecosystem Attributes

Assessing resilience is difficult because ecosystems are complex and dynamic, the responses to disturbances vary greatly in scale and duration, and many of the underlying mechanisms are not understood. This can be overcome by using four ecosystem attributes and their emergent properties as proxies for resilience (Welsh Government, 2016). Resilience arises from the interplay between the attributes, rather than from any one attribute in isolation (Latham et al., 2013) (Figure 2). The four attributes are diversity, extent, condition and connectivity:

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.

There are three measurable components of diversity: genetic characteristics, species and habitats. These diversity assessments draw on species and habitat data because NRW does not routinely collect genetic evidence.

Extent

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.

Size also determines resilience in the face of extreme events. Smaller units are at higher risk of random extinction due to catastrophic events, for example, extreme drought, storm, major pollution incident, fire, disease outbreak (Swift et al., 2010; Chase et al., 2020).

Condition

The condition of an ecosystem is investigated by collating evidence about both the biotic (biological) and abiotic (environmental) factors associated with a habitat or species. For example, biotic data could be collected about the presence, abundance, structure, function and range of habitats and species. Abiotic data relating to the status of environmental conditions relevant to the habitat or species could also be sampled, for example, water, soil and air quality.

The condition of habitats 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).

Connectivity

Connectivity refers to the links between and within habitats, which may take the form of corridors, stepping stones or patches of the same or related vegetation types.

Environmental factors such as geology, soil type or hydrological links affect sea / 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. Connectivity is a major driver for spatial variation which affects diversity and the abundance of living organisms.

Aspects of resilience

Ecosystem resilience is thought to be an emergent property of these four attributes, and may appear in three different ways, or aspects: adaptability, resistance, or recovery to/from disturbance. Adaptability was previously (e.g. in SoNaRR2016) listed as an attribute of resilience, but recent work has clarified the relationships of these terms, as shown in Figure 2.

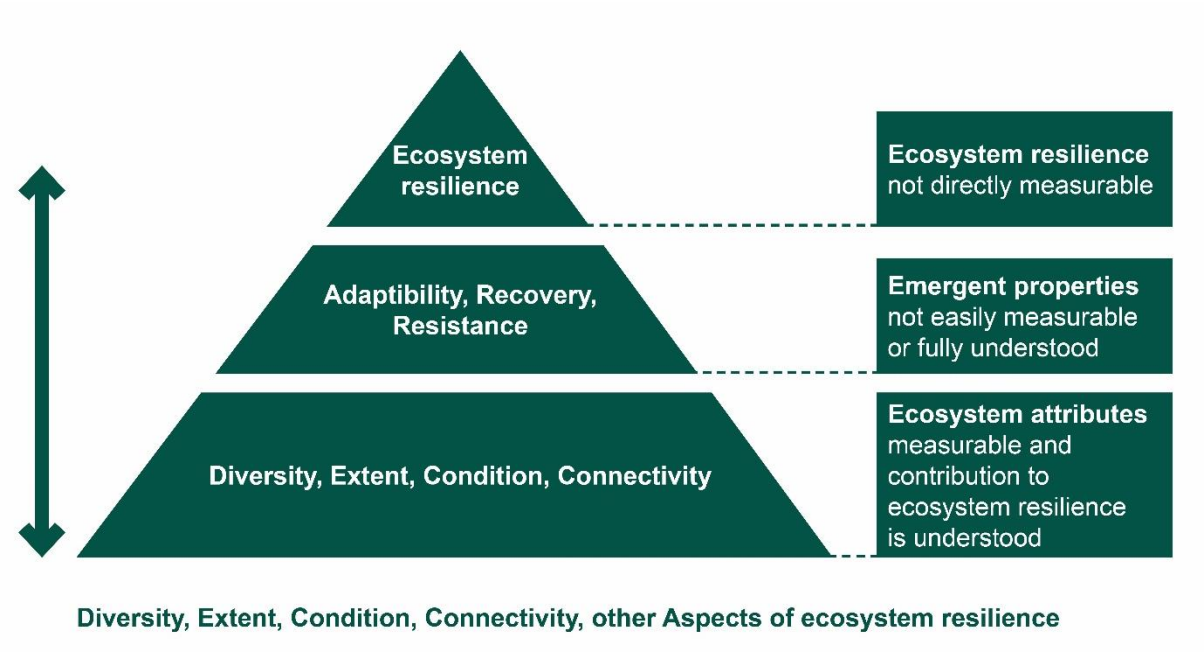

Figure 2 DECCA framework showing the relationship between the attributes and the emergent properties of resilience.

DECCA, or Diversity, Extent, Condition, Connectivity and other Aspect of ecosystem resilience, is used as an acronym to refer to this framework of ecosystem resilience. DECCA can be applied to environmental processes at different scales, habitats and land uses. This recognition of interconnectivity makes an approach based on resilience different to the traditional, more reactive responses in the management of natural resources**.** These attributes have been used for decades to guide the design of networks of marine protected areas in order to contribute to the overall health and resilience of the marine environment.

Assessing ecosystem resilience

In the State of Natural Resources Report 2020, resilience has been rated using expert judgement based on the best available evidence. 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 following criteria:

Diversity: Is biodiversity being maintained? What are the trends and historic losses? What are the main pressures or drivers for change?

Extent: How big is the ecosystem? What are the trends and historic losses? What are the main pressures or drivers for reducing extent?

Condition: Consider evidence for the quality of soils, air, water and biodiversity; and pressures including invasive non-native species, grazing regimes and harvesting intensity. Protected site condition assessments should also be included in the judgement.

Connectivity: This considers evidence for ecosystem fragmentation by looking at habitat corridors, stepping stones and islands, and the potential movement of species, water, energy and nutrients. There should be regard for limitations to connectivity such as soil type, hydrology and topography. In marine ecosystems surface current patterns, and the capacity for larvae dispersal is an important aspect of connectivity.

Urban ecosystems are poorly evidenced and mapped, so measures of SMNR were used instead of the DECCA framework. Eight measures were rated as sufficient, insufficient or variable in supporting a healthy human environment and a regenerative economy. The measures were air and water quality, flood risk, noise levels, green space, urban tree cover, biodiversity and the incidence of urban 'heat islands' (where urban areas are hotter than the rural surroundings).

National overview of ecosystem resilience

See Natural Resources Registers and ecosystem and cross-cutting theme chapters for more detail.

Diversity of ecosystems in Wales

Levels of ecosystem diversity are varied, but most lowland, upland, coastal and modified habitat types have seen a reduction over the last 100 years, with the rate accelerating from the 1970s onwards. If diversity continues to be lost then it may result in the collapse of ecosystems and their services (MacDougall et al., 2013)

Diversity of coastal margins and marine habitats

All five coastal ecosystems have been rated as having medium diversity, with physical constraints and other pressures affecting habitat succession and the diversity of species (Figure 3).

Intertidal and subtidal habitats make up the marine ecosystem and they both showed medium diversity (Figure 7).

Diversity of enclosed farmland

Diversity is low in arable fields and agriculturally improved land where intensive management has focussed on cultivating a small number of species.

Ancient hedgerows are highly diverse, while those planted after 1840 have medium diversity. The diversity of plants associated with them is variable. Conversely diversity for traditional orchards, parkland and wood pasture remains high (Figure 4).

Diversity of freshwater habitats

Human activity through the 20th Century has damaged the physical and biological diversity of lowland lakes, rivers and floodplains and are rated low, although marl lakes and ponds are rated as medium.

Upland lakes are generally rated as high and improving, with most having a good habitat structure and biodiversity that reflects the expected range of species. However, in upland rivers diversity has declined and is rated low (Figure 5 and Figure 6).

Diversity of mountain, moorland and heath

Lowland peatland and heathland are two habitats found at lower elevations that have retained a moderate level of diversity although significant functional and vegetation elements are absent.

Alpine and boreal heath and a matrix of other upland habitats, for example, acid grasslands and bracken stands, have declined to low diversity. The structure and species diversity of these habitats have become impoverished through long-standing environmental and land management pressures. Other types of upland peat and heathland habitats have medium diversity (Figure 8 and Figure 9).

Diversity of semi-natural grasslands

Lowland semi-natural grasslands have been damaged by human activity during the 20th Century, and large numbers of native grassland species are under threat, so these are rated low. Upland semi-natural grasslands have medium diversity (Figure 10).

Diversity of woodlands

Non-native woodland has low to medium diversity, reflecting the historic legacy of monoculture plantations. Despite movement towards more mixed species planting, 45% of woodlands are still dominated by just a few species.

Diversity of tree and shrub species has been rated medium to high for native woodland (Figure 11).

Diversity of species

Animals, plants and other organisms are key units of biodiversity and the evidence presented in the biodiversity chapter shows a mixed picture. For example, the average abundance of butterflies has declined in Wales since 1976, but the average trends in mammals and some birds are increasing (Welsh Government, 2019b; Harris et al., 2019). The overall decline in numbers from the 1970s is accompanied by decreases in distribution, with 39% of species found in fewer places than in the previous two decades. Serious declines have been reported for some species, and 17% of species in Wales are at risk of extinction (Hayhow et al., 2019; Welsh Government, 2019b).

Soil organisms (biota) are vital for nutrient cycling and plant growth (George et al., 2019). Monitoring shows a decline in soil animal and microbial diversity across all land uses between 2013 and 2016, but especially on intensively managed land (Emmett et al., 2017).

Extent of ecosystems in Wales

Semi-natural habitat accounts for 640,827 hectares (ha), or 31% of the land area of Wales (NRW, 2018), and there is a spatial pattern of semi-natural habitat loss, with less remaining in lowland areas than upland ones. These losses will have a significant bearing on resilience, although the full impacts may take a long time to be fully realised because of the lag between habitat loss and species extinction (Kuussaari et al., 2009).

Extent of coastal margins and marine habitats

Most of Wales's coastal margin and intertidal habitats are either low or medium in extent, mainly because of shoreline modifications and coastal squeeze from rising sea levels. The extent of sub-tidal habitats is high with only a limited amount of loss due to development (Figure 3 and Figure 7).

Extent of enclosed farmland

Substantial areas of traditional orchards, parkland and wood pasture have been lost. Arable land and hedgerows have shown historic losses although these have now either stabilised or slightly increased. All these habitats were rated as medium extent. The land cover for agriculturally improved land is extensive so this modified habitat was rated high (Figure 4).

Extent of freshwater habitats

River habitat has been lost through historic and current management practices including hard engineering and water abstraction. Extent was rated moderate for upland rivers, and lowland ones with their associated floodplains were rated low.

The number of ponds has declined by 64% and the extent of marl lakes and lowland lakes is low. The extent of upland lakes was rated high (Figure 5 and Figure 6).

Extent of mountain, moorland and heathland

The amount of lowland heathland and peatland has declined considerably due to management practices that modify plant communities and change the type of habitat. The extent of these habitats was rated low.

Upland heath, peatland, and rock habitats have been lost through past and current management practises and there now remains only medium extent. The wider matrix of upland habitats was rated high for its coverage (Figure 8 and Figure 9).

Extent of semi-natural grassland

The amount of lowland semi-natural grassland has significantly declined through conversion to other habitats by agricultural intensification and its extent was rated low. The expanse of upland semi-natural grassland has not changed very much and was rated high (Figure 10).

Extent of woodland

Wales has extensive conifer plantations so the land cover for non-native woodland is high, and the extent of native woodland is medium, with 51% of native stands in woodlands greater than 20 ha (Figure 11).

Condition of ecosystems in Wales

Most habitats are in low condition, and the rest are moderate at best. All are subject to multiple and complex pressures which adversely affects the quality of the ecosystem.

The freshwater habitats are mainly affected by nutrient enrichment and physical modifications. The condition of terrestrial habitats is variable at a site level with some good quality areas.

Condition of coastal margins and marine habitats

Intertidal habitats and most coastal habitats are in a low condition. The condition of saltmarsh and sub-tidal habitats are medium (Figure 3 and Figure 7).

Condition of enclosed farmland

The low condition of parkland and wood pasture, traditional orchards, arable land, agriculturally improved land and hedgerows has mainly been caused by intensive high-input agricultural management (Figure 4).

Condition of freshwater habitats

Lowland and marl lakes and ponds are susceptible to damage from past pollution events, even when the pressure causing it has stopped, as pollutants can be continually recycled within the water body and its sediments. Lowland rivers and

floodplains have extensive modified habitat which impacts their quality. The condition of all these habitats is low.

Upland rivers and lakes are in medium condition although they are vulnerable to atmospheric deposition of nitrogen and other pollutants (Figure 5 and Figure 6).

Condition of mountain, moorland and heath

Lowland peatland and heathland are in low condition. Lowland peatlands often occupy a fragment of their original footprint and they suffer disproportionate “edge effects” further reducing condition and effective area of habitat.

Upland peatland and rock habitats are in a medium condition whereas, alpine and boreal heath and the matrix of wider upland habitats including acid grassland and bracken stands are rated low. These problems are related to reactive nitrogen deposition, overgrazing and possible effects of climate breakdown (Figure 8 and Figure 9).

Condition of semi-natural grassland

Lowland semi-natural grassland is in low condition and upland ones are medium. Insufficient management and land abandonment coupled with the impacts of climate breakdown and air pollution are the leading causes (Figure 10).

Condition of woodland

Most native and non-native woodlands are in medium ecological condition, however, tree pests and the lack of veteran trees and deadwood remain an issue for resilience (Figure 11).

Condition of soils

Topsoil carbon concentrations have been monitored across Wales. Recent analysis shows topsoil carbon was stable in woodlands and agriculturally improved land, although there was a significant decline in upland habitats (Alison et al., 2020).

Connectivity of ecosystems in Wales

In Wales connectivity is at its lowest in lowland habitats where the landscape has been “simplified” by the loss of semi-natural habitats and intensively managed land dominates. Also, connectivity between and within ecosystems has decreased with habitat damage and loss, which has affected both species and habitat distribution and functionality (Rogan and Lacher, 2018).

Connectivity of coastal margins and marine habitats

The connectivity of coastal saline lagoons and shingle is low. The lagoons have poor connectivity with adjacent habitats and shingle is fragmented by coastal defences. Sea cliffs, sand dunes and saltmarsh have medium connectivity, and the connectivity between saltmarsh transition zones is a concern.

Connectivity for sub and inter-tidal marine habitats is high (Figure 3 and Figure 7).

Connectivity of enclosed farmland

Agriculturally improved land and hedgerows have high connectivity. Arable land and traditional orchards have low temporal and spatial connectivity, whereas for parkland and wood pasture it is medium (Figure 4).

Connectivity of freshwater habitats

Connectivity is very important for the functioning of floodplains and lowland rivers. They have been severely damaged by structural flood protection, river straightening, disconnection of floodplain wetlands, agricultural land-use and urbanisation over the past two centuries and are rated low.

Upland and lowland lakes have high connectivity and marl lakes which have experienced very little loss of connectivity and are also rated high. Although the number of ponds has declined, it is possible to retain a medium level of connectivity because so many pond species are good colonisers.

The inaccessibility of upper reaches of upland rivers has afforded them some protection from human activity and their connectivity is medium (Figure 5 and Figure 6).

Connectivity of mountain, moorland and heath

Lowland peatland and heathland are fragmented. They have low connectivity due to historic widespread loss of habitat. Upland peatland, rocky habitats and the matrix of upland habitats is rated medium whereas alpine boreal heath is low (Figure 8 and Figure 9).

Connectivity of semi-natural grassland

Generally lowland semi-natural grassland is fragmented although the connectivity does vary locally so a few well-connected and resilient grassland landscapes remain. Perhaps unsurprisingly, these better connected areas support populations of scarce or threatened grassland plants and animals which have vanished from many other areas (Figure 10).

Connectivity of woodlands

Non-native woodlands are usually designed at a landscape scale and connectivity is high. Native woodland has medium connectivity and is often supported by adjacent semi-natural habitats, for example, hedgerows and mountain, moorland and heath communities in upland areas (Figure 11).

Resilience of urban ecosystems

Because urban ecosystems have some fundamental differences to others, we have assessed their resilience in terms of ecosystem services. The resilience of urban

ecosystem services is mostly variable, and declines are predicted for services currently considered sufficient. Most of the Welsh population live in urban environments so this level of insecurity is likely to impact a lot of people.

Urban air and water quality

Urban air quality is impacted in areas with busy roads, and water quality depends upon the infrastructure to manage run-off and local flood events. Flood risk is likely to increase due to wetter winters and the increased frequency of storm events caused by climate breakdown. The resilience of air and water resources and flood events is rated variable.

Urban green space and biodiversity

Accessible public and private green space is insufficient and declining, although evidence is patchy. In 2013, the average urban tree cover in Wales was 13% (NRW, 2016), with lower values recorded in deprived urban areas and coastal settlements. The resilience of urban tree canopy cover and their diversity is rated insufficient.

Urban biodiversity is not routinely monitored, so no data was available to evaluate it at a town or city level. Based on expert opinion the resilience of urban biodiversity was rated as variable.

Urban heat and noise

The current level of resilience in Welsh cities to the impacts of increased urban heat on human health is considered sufficient, but it is anticipated that this will decline as the frequency of hotter and drier summers increases.

Road traffic is the major contributor to urban noise, and greater noise levels are recorded in deprived areas. The resilience of the built environment to noise was also variable.

Resilience by types of ecosystems

The figures below illustrate the levels of diversity, extent, condition and connectivity across different ecosystems. Ecosystem resilience cannot be measured directly, but general messages on its state can be inferred from these assessments. There is no graphic for the urban ecosystem because of the different assessment method.

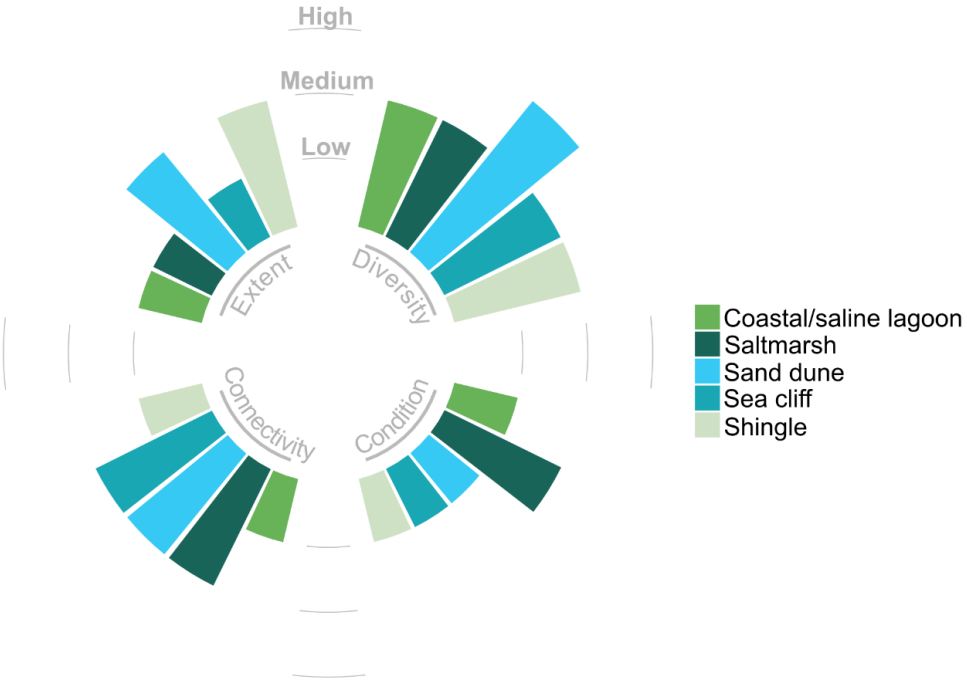

Figure 3 Attribute ratings for each type of coastal margin habitat

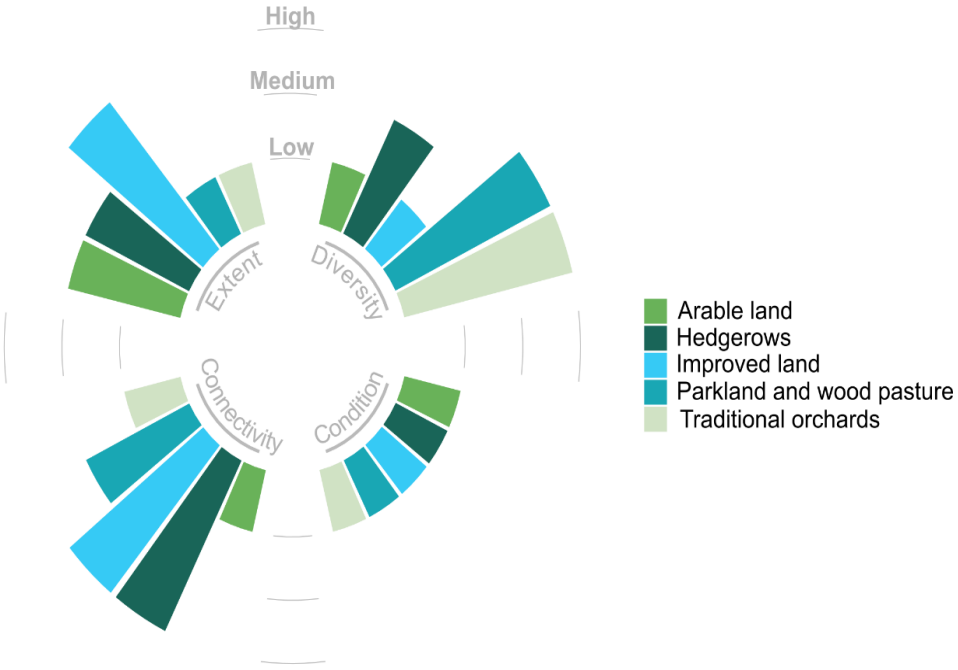

Figure 4 Attribute ratings for each type of enclosed farmland habitat

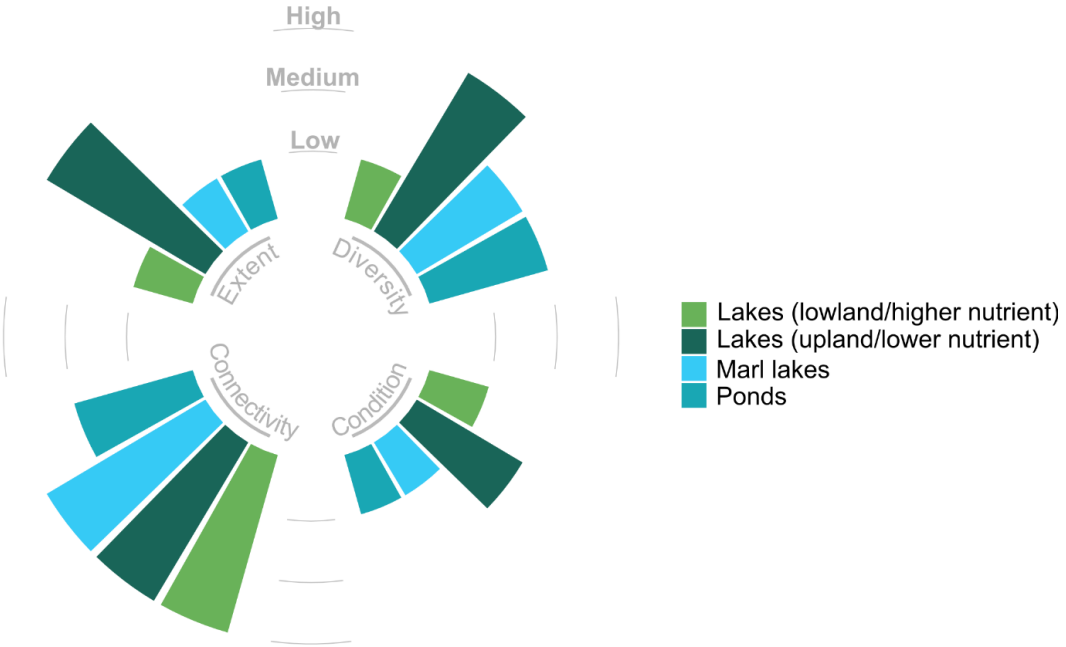

Figure 5 Attribute ratings for each type of standing waters habitat

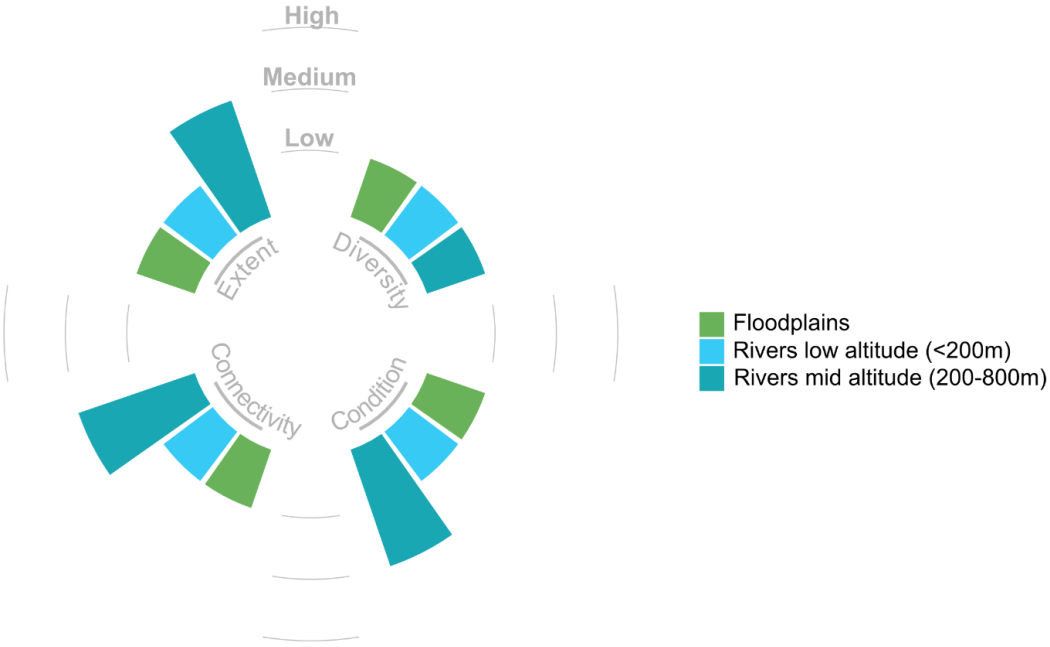

Figure 6 Attribute ratings for each type of running water habitat

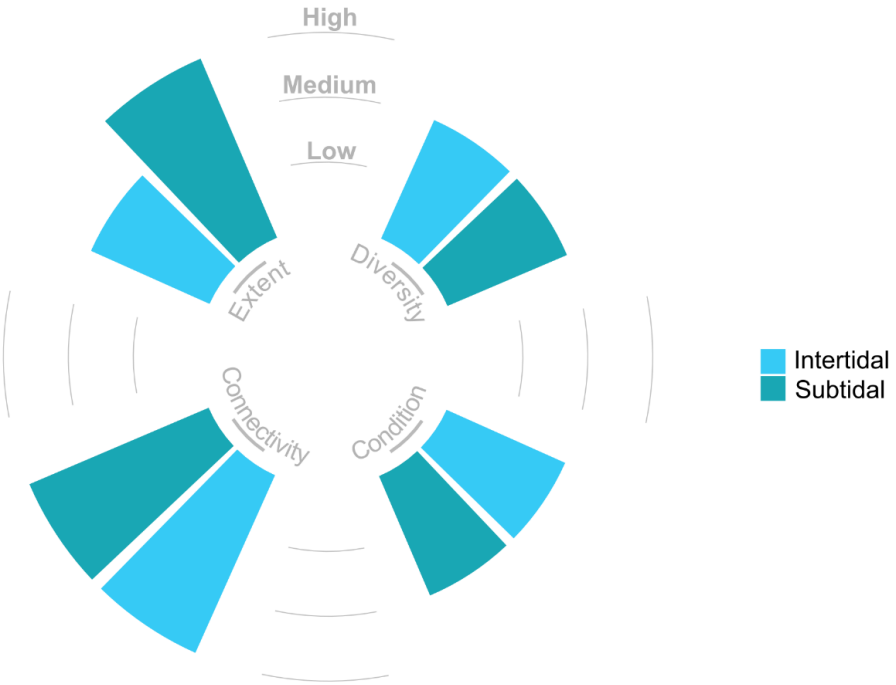

Figure 7 Attribute ratings for each type of marine habitat

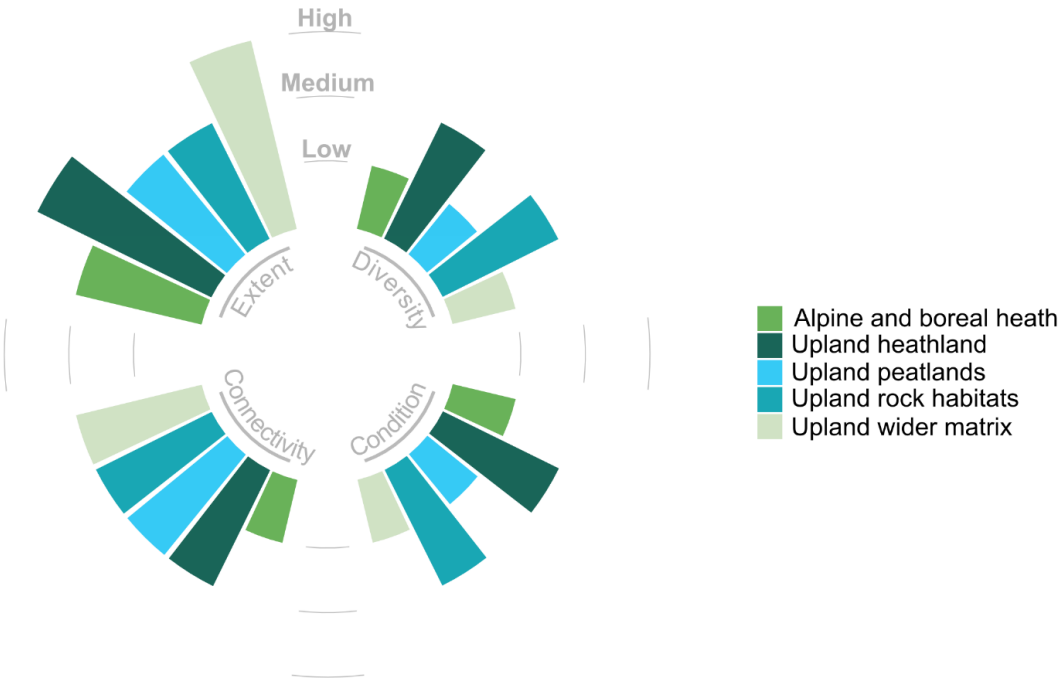

Figure 8 Attribute ratings for each type of upland mountain, moorland and heath habitat

Figure 9 Attribute ratings for each type of lowland moorland and heath habitat

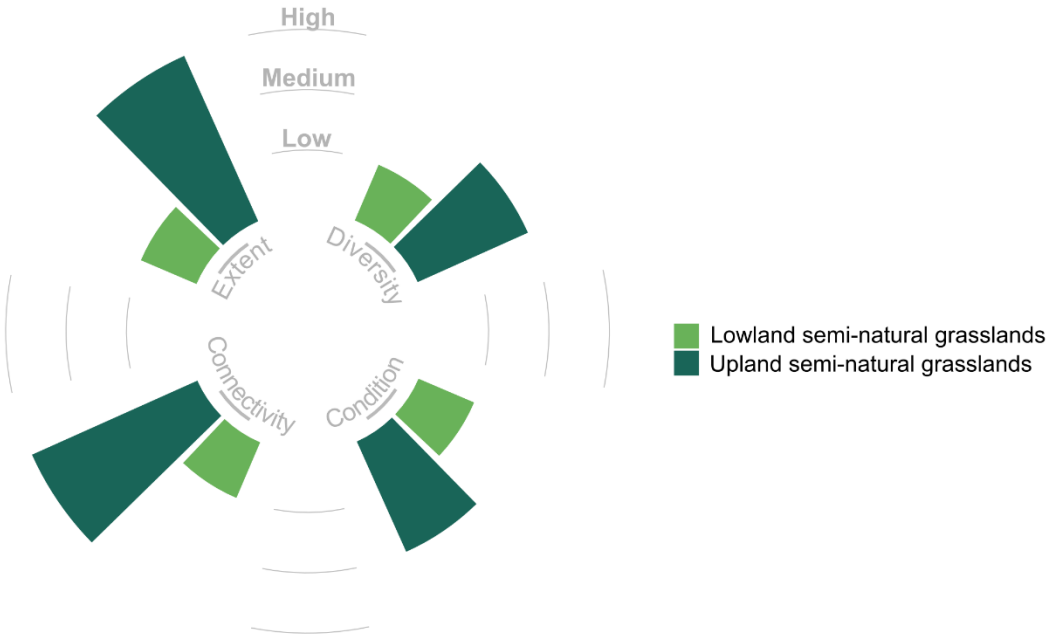

Figure 10 Attribute ratings for each type of semi-natural grassland habitat

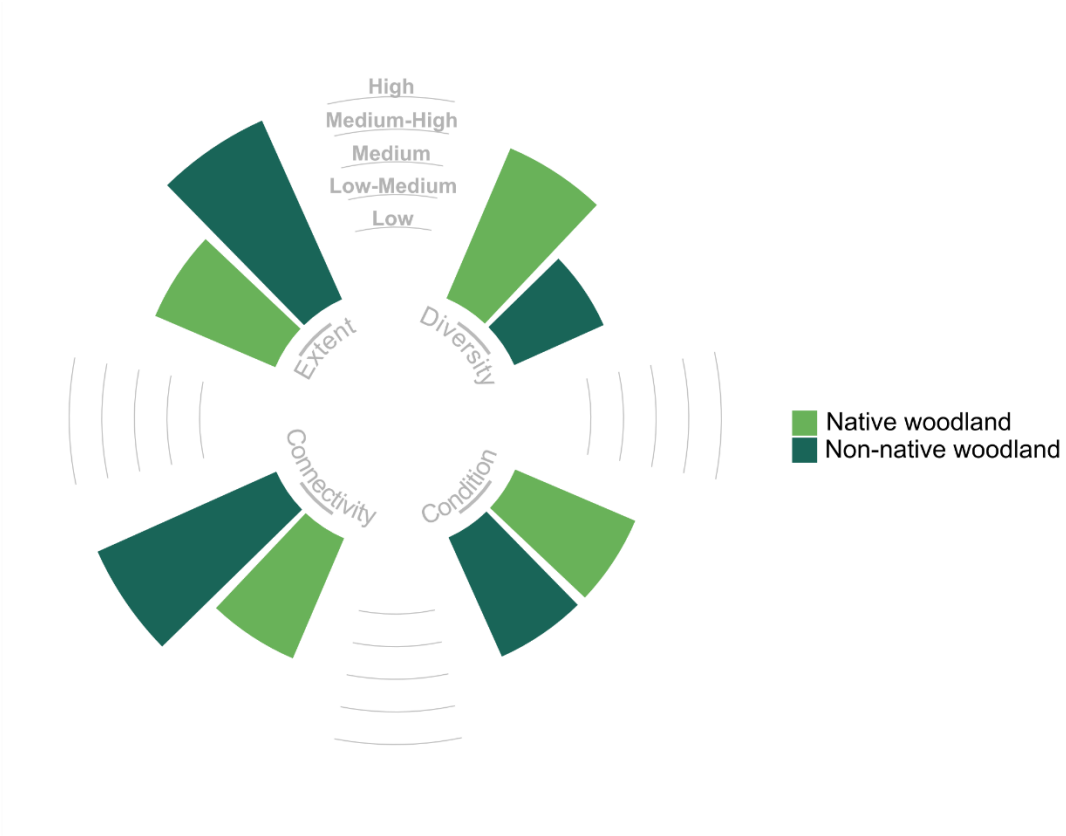

Figure 11 Attribute ratings for types of woodland habitat

Case study: Developing a way to assess ecosystem resilience

In this report the attributes of resilience have been assessed as Low, Medium or High using evidence-based expert judgement, allowing inferences about the overall state of the resilience of different ecosystems. There are few relevant published tools or methods available to measure ecosystem resilience at a national scale. To address this evidence gap NRW has developed experimental maps to show the Current Relative Value of Resilience (CuRVe) at a 1-kilometre square resolution (Figure 12).

The CuRVe Condition map was modelled using terrestrial and freshwater datasets for soil erosion risk, air and water quality, invasive non-native species, positive plant indicator species and protected sites assessments. The resulting map shows that the condition of ecosystems across Wales is relatively moderate although there are patterns of variability across the landscape with “cold spots” of low ecological condition (paler areas).

River corridors in South-East Wales are particularly noticeable because their relative resilience value is less than 25 and the larger river channels appear as pale lines on the map. The inland areas of Pembrokeshire and Carmarthenshire also have sizable patches of poor condition which we assume implies low resilience. These lowland areas are subject to intensive land-use and the datasets appear to demonstrate the

impacts of these activities. Very few areas in Wales have been classified with levels of relative resilience values greater than 60.

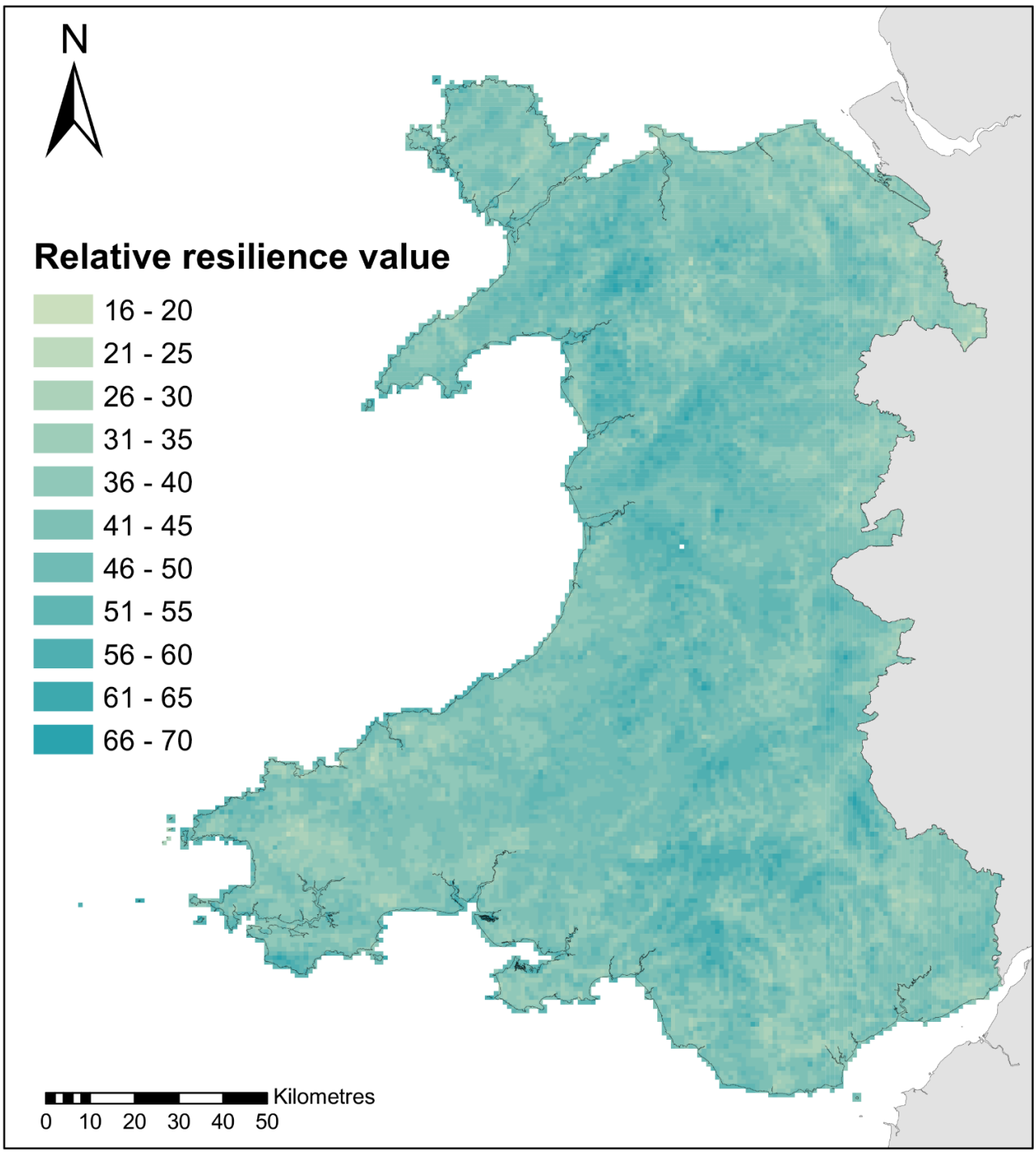

Figure 12 Relative patterns of ecosystem condition

These maps are a work in progress. A technical report detailing the analysis methods is available (Naumann and Medcalf, 2020) and soon the maps will become available on the NRW Wales Environmental Information webpage.

The SoNaRR2020 assessment of ecosystem resilience

Assessing ecosystem resilience is complex, and tools need further development, however, by collating the expert judgements for each ecosystem we have detected the patterns of resilience emerging across the national landscape (Figure 13 - Figure 16). These figures show the number of habitats scoring high, medium or low status for each resilience attribute. The majority are low or medium and this is very worrying because such levels compromise both vital ecosystem services and biodiversity recovery and leave Wales ill-equipped to cope with the effects of the climate crisis and other disturbances.

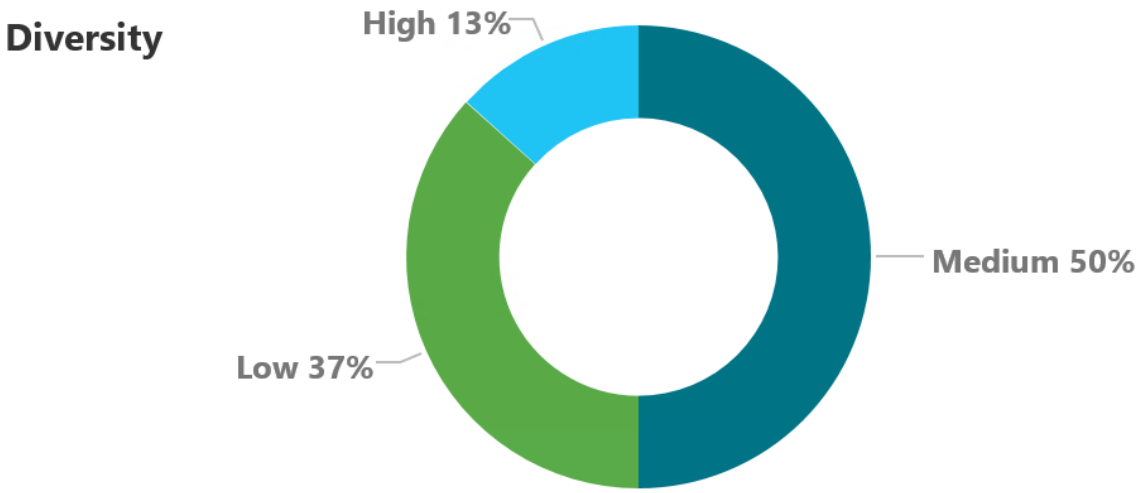

Figure 13 Status of diversity in Welsh habitats from which resilience can be inferred

Only 13% of Welsh habitats are considered to have high diversity levels. The ratings indicate that ecosystems are not resilient, and many species are not recovering (Figure 13).

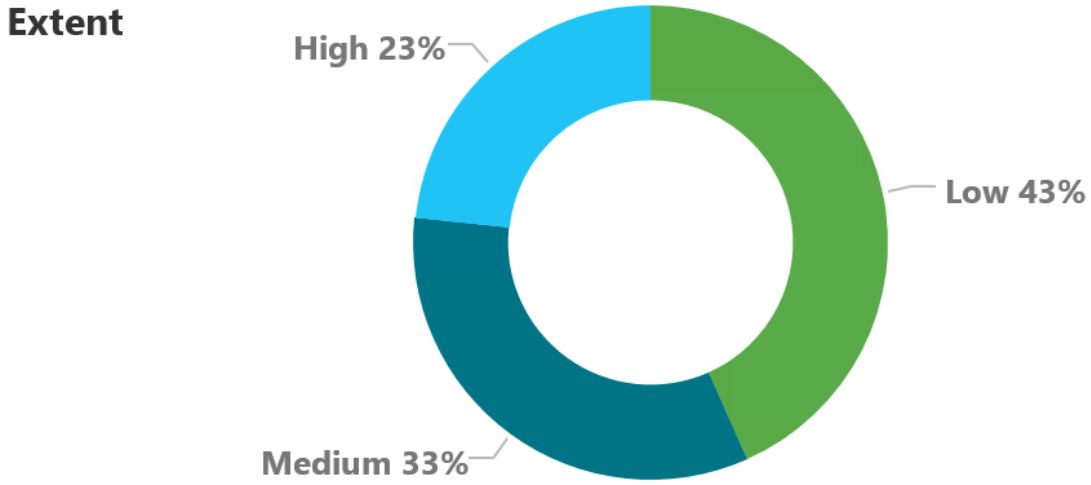

Figure 14 Status of extent for Welsh habitats from which resilience can be inferred

The small patch size for at least 43% of Welsh habitats implies low resilience. There is some evidence to show that the rate of loss has slowed for some habitats since the 1970s, but these results still imply significant impacts on resilience. Careful planning for extensive habitat creation and restoration is required to mitigate the effects of these losses (Figure 14).

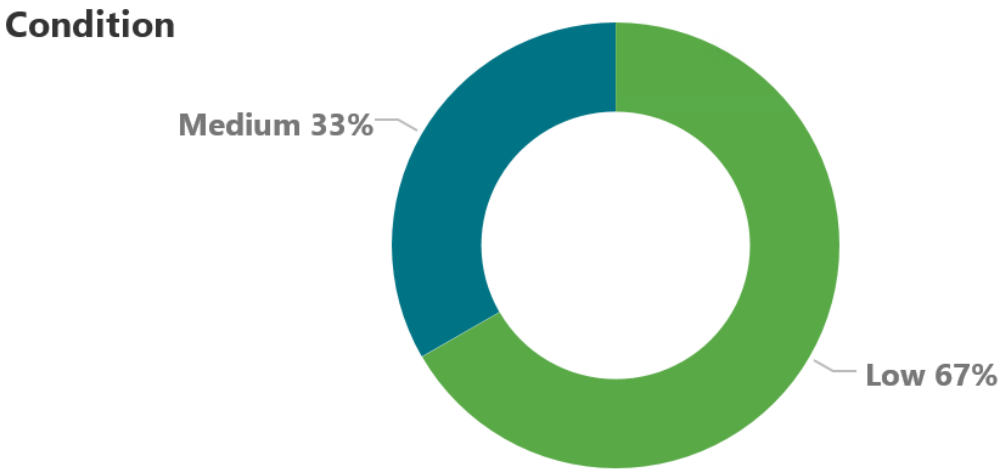

Figure 15 Status of condition for Welsh habitats from which resilience can be inferred

The condition of habitats is affected by multiple and complex pressures and in many instances the impacts of historic changes to land-use are still being seen. Condition is low (67%) to medium (33%) across Wales in all ecosystems with none of the habitats rated high (Figure 15).

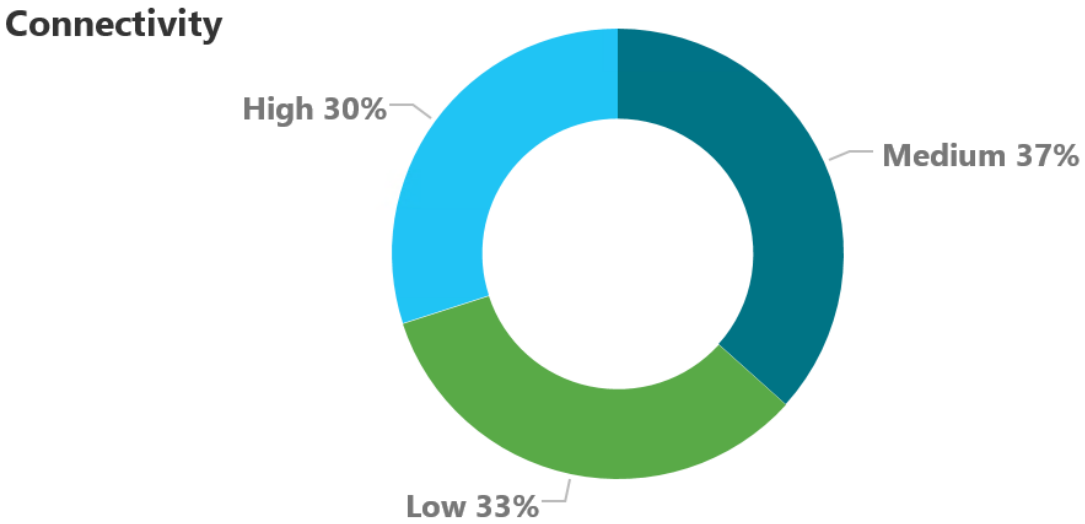

Figure 16 Status of connectivity for Welsh habitats from which resilience can be inferred

Land and water management practices that reduce connectivity, make species less able to maintain populations, or resist or recover from local or large-scale environmental disturbances, for example drought and flooding (Figure 16).

Improving ecosystem resilience

The objective of SMNR is to build resilient ecosystems supplying ecosystem services which help Wales meet its well-being goals for a sustainable future. To achieve this objective there is an urgent need to transform socioeconomic systems so that they work more like natural regenerative systems that are able to respond to feedback in relation to environmental capacity. Key messages relating to the necessary changes are discussed in each of the SMNR aims chapters. A joined-up, strategic approach to fulfilling these aims would improve Wales's preparedness for a world predicted to have increasingly unstable environmental conditions caused by the climate crisis.

Resilience and sustainability are the outcomes of building healthy and regenerating ecosystems. Ecological resilience can be improved by maintaining and enhancing those elements of land-cover that aid the recovery of biodiversity and restore functionality to ecosystems.

The opportunities to advance each attribute of resilience are discussed separately, although they are inter-dependent and require an integrated and strategic approach.

Improving diversity

Ecosystems should be naturally diverse, but genetic variation, species richness, habitat variety and structural diversity has declined at varying rates over time due to human activity. It is critical that current levels of diversity are at least maintained, and that there is no further loss.

Structural diversity in habitats can be maintained or created through appropriate management regimes, for example grazing, management of invasive non-native species, reinstating hydrological conditions and managing ecological succession.

Effective management should provide conditions that support whole lifecycles of species to halt the decline in biodiversity, reduce local extinction of species and increase population abundance. In some cases, the management might include the re-introduction of a native "ecosystem engineering" species that can create, maintain or modify habitats to the wider benefit of other native species, such as water vole in rivers, and *Sphagnum* mosses in peatlands. However, in most cases where appropriate conditions are reinstated, biodiversity will increase, and the ecosystem is able to self-restore.

Conifer plantations and agriculturally improved grassland are types of heavily modified or artificial habitats that dominate extensive areas of Wales. These habitats are typically based around a small number of species that have been selected for their productivity. There is great potential to improve the species, genetic and structural diversity of these areas. In many cases there will also be financial savings, for example, multi-species grassland promotes greater soil health and requires less intensive management (Weigelt et al., 2009). Some plant pathogens that cause disease, are host specific, so the scale, transmission rate and the financial impact of an outbreak can be reduced in creating a more mixed species crop. There are challenges around this, with further research needed to determine which species are

appropriate and understand the trade-offs between productivity and the benefits of resilience. Progress is already being made in this regard with forest resource planning, including NRW publishing its silviculture guide to improving the structural diversity of Welsh forestry plantations (NRW, 2017).

Improving extent

The extent of semi-natural habitats in Wales has been significantly depleted by intensive agricultural practices and expansion of the built environment footprint and its associated infrastructure both on land and at sea.

Rebuild extent through three-pronged approach to land management:

- maintain existing semi-natural habitat
- enhance, restore and create habitat through strategic landscape-scale programmes
- research and promote sustainable agricultural, forestry and fisheries practices that help to maintain, restore and create semi-natural habitats

Improving condition

Condition is the attribute most frequently assigned as ‘low’ across habitats in this assessment, especially in lowland terrestrial ecosystems. It can be improved by putting in place appropriate policies, sustainable land management strategies (Oberč and Arroyo Schnell, 2020) and the effective regulation of activities acting as drivers or pressures on a wider scale.

Mechanisms are generally in place to control these activities, but there is a need to ensure that they effectively meet all the challenges. There are a set of wider factors that impact condition that are harder to control, including atmospheric pollution, plant diseases and invasive non-native species. The solutions to these issues may also require policy co-operation at an international level rather than just in Wales.

Improving connectivity

Connectivity is usually the best understood of the resilience attributes, especially when considering the distribution of, for example, woodlands across a landscape or the hydrological processes in a freshwater or marine ecosystem.

In addition to acting to increase the quality of connectivity for a specific habitat, there is a need to better understand the scale of relationships between ecosystems, and landscape permeability, when prioritising action.

Work should be targeted at developing functional habitat networks that operate across the landscape and build on existing areas of high connectivity and quality. This could include enlarging habitat areas, developing buffer strips, creating corridors (which may include transport corridors, footpaths and bridleways, rivers and streams) and habitat “stepping stones” (Cole et al., 2020). Also, the removal of barriers to fish migration in rivers and streams and improving overall management of

the landscape. There is also a need to create or support existing mechanisms that encourage landowners to collaborate in improving the environment.

Resilience and the sustained delivery of ecosystem services

The Millennium Ecosystem Assessment (2005) grouped ecosystems services into four categories: regulating, provisioning, cultural and supporting. The levels of services provided by each ecosystem are discussed in the current State of Natural Resources ecosystem chapters (NRW, in prep).

There are complex interdependencies between people and ecosystems; economies and societies totally depend on them to provide people with a hospitable climate, clean water, food, materials and numerous other goods and services. The continued delivery of these services depends upon resilient and functioning ecosystems, so maintaining or building resilience is central to the sustainable management of natural resources (SMNR). The following case studies demonstrate that by enhancing the diversity, extent, condition and connectivity of semi-natural habitats, services are not only sustained but very often additional benefits are secured.

Case study: Pontbren farmers working with natural processes (WWNP)

The WWNP project studied the outcomes of experimental work organised by a group of farmers in the Pontbren catchment to plant cross-slope hedgerows and shelter belts. It was found that this change to land management diminished the speed and volume of rainfall run-off and reduced the risk of flooding for local communities. Other studies have found that similar planting schemes also improved water quality in rivers and reduced the levels of polluting nitrates in ground water (Woodland Trust et al., 2013).

Case study: Locking up carbon for decades using peat bogs

Landowners are working together with the New LIFE for Welsh Raised Bogs project to capture carbon and to help Wales meet its carbon emissions targets. The 900 hectares of restored peatlands will also purify water and provide habitat for rare wildlife.

Case study: Safeguarding the Welsh coastline with sand dunes

Sand dunes are a popular place for leisure activities and they also fulfil an important function in safeguarding nearby settlements from coastal erosion and flooding. The Dynamic Dunescapes project will work with wildlife charities to restore key Welsh sand dunes and build their biodiversity.

Case studies: Two examples of habitat restoration

Native woodland extent and diversity has been improved on Planted Ancient Woodland Sites (PAWS) in the Radnor Forest where non-native larch trees were diseased and had to be cleared. The PAWS were re-stocked with sessile oaks of local provenance.

A concrete ford across the Afon Eden was acting as a silt trap and a partial barrier to migratory fish. It was removed and the riverbed was restored by re-seeding with gravels and boulders to improve environmental conditions for critically endangered freshwater species.

How to improve resilience and sustain Wales's ecosystem services

All life is supported by a vast network of interdependent ecological processes which rely on an array of species to maintain the functionality and stability of ecosystems. Human existence is determined by these slender threads of circumstances and it is essential that these threads are resilient.

Wales does not currently have coherent and resilient ecological networks which function synergistically as a whole to support the wider environment and maintain the processes, functions and structures of habitats and species across their natural range (Laffoley et al., 2006). These "broken threads" make it doubtful that ecosystems will be capable of coping with the challenges of climate change and continue to deliver goods and services into the future. To address this crisis a significant step change in the style, pace and scale of action is urgently needed. It will also require more partnership working.

Changes to land and sea use should be supported at a landscape scale and pressures and impacts reduced. This will:

- protect existing ecosystems and improve their condition and functioning
- increase the extent of semi-natural habitats
- enhance connection within and between ecosystems by creating connectivity patches and habitat corridors
- restore and create semi-natural habitats
- reduce and better manage the pressures and demands on ecosystems and natural resources, focusing on sustainable resource use and efficiency
- diversify production systems

Resilience is still a complex and evolving experimental concept for managing ecosystems in the context of a period of major environmental change. A recent literature review confirmed that we can use the DECCA concept of ecosystem resilience to develop a framework to help land managers progress projects and plans that integrate resilience with the sustainable management of natural resources (Beller et al., 2019; Crick et al., 2020; Garrett, 2020).

Resilience is a variable quality, and resilience to one kind of pressure may not necessarily confer resilience to another. However, relative resilience can still be built. Figure 17 shows the direction of travel required to reverse this precarious situation and move towards improved resilience.

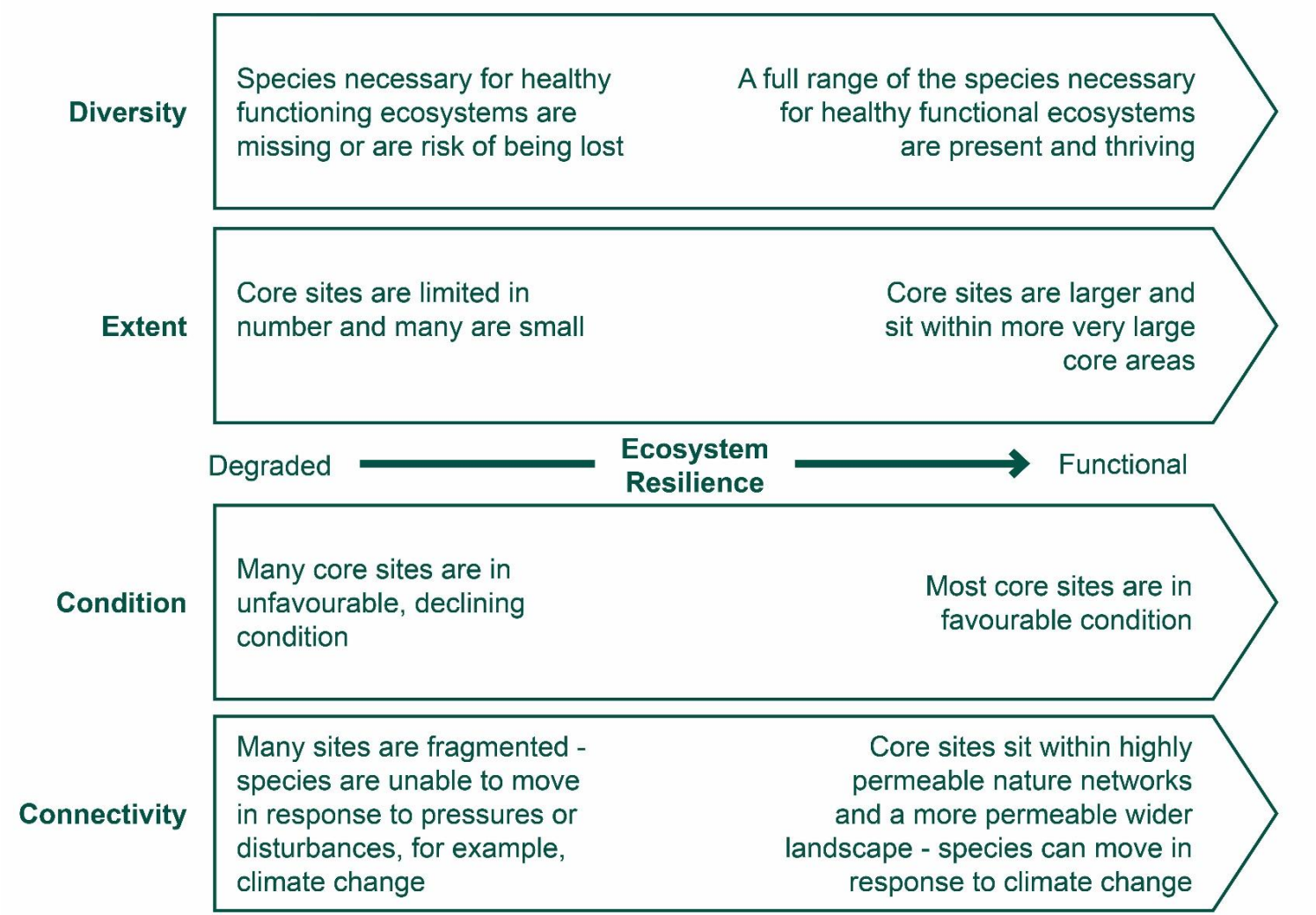

Figure 17 Direction of travel for building ecosystem resilience using the four attributes Adapted from Crick et al., 2020

Note on Figure 17: Core sites to be interpreted as protected sites that are already been designated, for example, Sites of Special Scientific Interest. Core areas have no standard definition but would depend on local priorities

Current Welsh policy context for building resilience

There are seven goals set out in the Well-being of Future Generations Act 2015, and the second is to have ‘a resilient Wales’ that supports social, economic and ecological resilience through maintenance and enhancement of a biodiverse natural environment and healthy functioning ecosystems.

This links to the objective of the sustainable management of natural resources (SMNR) as described in the Environment (Wales) Act 2016, where it states NRW must “maintain and enhance the resilience of ecosystems and the benefits they provide now and for future generations”.

These two recent pieces of legislation are welcome. There is a need to be more ambitious in the way they are implemented and to power up the provision for the existing legislative framework.

All public bodies share a duty to maintain and enhance biodiversity and in so doing promote the resilience of ecosystems under Section 6 of the Environment (Wales) Act. NRW is also required to use the principles of SMNR to maintain and enhance the resilience of ecosystems and the benefits they provide now and for future generations. The application of these principles greatly enhances NRW’s ability to meet its Section 6 duty. The delivery of this duty by other public bodies could be improved if mechanisms existed to encourage them to embrace the same principles.

Section 16 of the same Act enables NRW to enter into agreements with any person who has an interest in how they manage their land for any activity within the remit of NRW. With the correct levels of resourcing, these agreements offer a significant opportunity to work in partnership with a more diverse group of stakeholders on SMNR activities that cannot be agreed through other mechanisms. For example, protection of SSSI qualifying features while they await notification, agreements on non-agricultural land, specialist management techniques for sensitive species and habitats, habitat restoration and the creation of buffer sites.

Section 23 gives NRW the power to conduct experimental projects to develop or apply new or modified methods, concepts or techniques, and to develop or test proposals for regulatory change. Adaptative management techniques could be more widely adopted if a more agile process for using these powers was developed.

The Natural Resources Policy (Welsh Government, 2017) is designed to drive the delivery of the goals of the above two new acts. This policy document and the Nature Recovery Action Plan (Welsh Government, 2020a) state the need to proactively develop resilient ecological networks (REN). RENs are defined 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.”

The Convention on Biological Diversity (1992) Strategic Plan for Biodiversity and the associated Aichi biodiversity targets (Welsh Government, 2019a; HM Government, 2019) recognise that resilient ecological networks are key to delivery for biodiversity recovery and retaining ecosystem services during a changing climate. Nature-based solutions to address both challenges should contribute wherever possible to maintaining and enhancing these networks. Consideration should be given to the governance of networks and the mechanisms for supporting their management objectives and longevity. The IUCN recommends exploring a number of mechanisms, for example, legal protection of the network planning control, land-use planning and zoning, management agreements and the role of incentives and disincentives (Hilty et al., 2020). Simple measures might include regulation to enhance existing corridors, for example, vegetation buffer strips are allowed to develop along river corridor marginal zones.

Future land management strategies and planning development policies will play a vital role in supporting ecosystem resilience and nature recovery (Welsh Government, 2018; 2020b). It will be important to draw on relevant evidence from Area Statements (NRW, 2020a) and mobilise geospatial and other datasets to support strategies and other decisions. Stakeholder engagement is key to working together to achieve mutually beneficial outcomes. The Area Statement process for mapping and costing opportunities has great potential for securing their buy-in.

Making the most of environmental assessment, regulation, good practice and standards

An early understanding of the potential environmental effects of proposed plans and projects helps to reduce or avoid adverse effects and maximise beneficial ones. Depending on the type of proposal, opportunities to modify a project or plan are identified through environmental assessment processes: Strategic Environmental Assessment (SEA), or Environmental Impact Assessment (NRW, 2020b). These processes are applied to many sectors: forestry, water management, agriculture, and town and country planning. Both NRW and local authorities should identify opportunities to integrate actions that would maintain and enhance biodiversity and the resilience of ecosystems at the outset.

Project and plan managers currently compile assessments based on relatively old guidance, for example the SEA guidance published by the Office of the Deputy Prime Minister (2005) pre-dates the Environment (Wales) and the Well-being of Future Generations Acts and does not incorporate those legislative aims or principles. Updated third-party guidance for Welsh assessments would promote and embed the sustainable management of natural resources in project and plan development.

Regulatory measures are in place to provide minimum standards of environmental conditions. An exploration of the benefits of raising the regulatory floor could be an important part of any post-EU exit review of these regulations. Most sectors also have long-standing voluntary guidance and standards for good practice. These could contribute to building resilience, but more evidence should be gathered to assess uptake, compliance and barriers to adoption.

Regulatory authorities in other countries show that stakeholder engagement is higher when the concept of building ecosystem resilience is used as a lens to review catchment management plans (Namoi CMA, 2013 Beller et al., 2019). This provides an opportunity to refresh engagement and develop new working methods that use the principles of SMNR to achieve its objectives. These approaches could also apply to revising and developing environmental standards and good practice guides.

Sector support for adopting nature-based solutions to build resilience

Transformative change is required from all sectors and this could be achieved through support mechanisms that build:

- wider understanding of the importance of nature-based solutions and how they might be applied using the global standards (IUCN, 2020)
- the widespread adoption of good practice guidance and environmental standards
- integrated policy interventions that support desirable environmental behaviours and promote partnership working using the principles of SMNR
- ability for conflicting priorities to be resolved, for example tree planting on existing semi-natural habitats
- regulatory and technological fixes that reduce and modify pressures

Each sector must be engaged and effective backing given using suitably tailored messages, advice, training, tools and a long-term support structure including funding strategies that provide for a longer time period than the currently typical three years. The management of the protected sites network and the Welsh Government estate could lead by example in demonstrating the multiple benefits of this approach.

Preparations for post-EU exit arrangements are a timely opportunity to create land management schemes with ecosystem resilience at their heart, and which create a pathway to the recovery of biodiversity. Such schemes would also need to support collaboration between land managers. The management of ecosystem services to promote the conservation of natural resources could also be incentivised in the marketplace though public and / or private investment.

Case study: Award winning Greener Grangetown shows the multiple benefits of retrofitting sustainable urban drainage systems

The project planted trees in public spaces and created roadside rain gardens to catch, clean and divert rainwater directly into the River Taff instead of collecting and pumping it eight miles to a treatment works in the Vale of Glamorgan where it would be discharged out to sea.

The permeable drainage surfaces and planting schemes also led to reduced noise pollution, increased biodiversity, improved air quality and additional greenspace for residents.

Changing the style, scale and pace of delivery

Recent research shows that it is not too late to “bend the curve” on biodiversity loss (Leclere et al., 2020), however, to meet the challenge, Wales needs to immediately raise its ambition and work at a landscape scale at a much faster pace commensurate with the transformative changes needed. Without Specific, Measurable, Achievable, Realistic and Timely (SMART) targets for ecosystem and biodiversity recovery it will be difficult to judge progress and the effectiveness of interventions. Also delay or continued narrow-scale thinking that isn’t consistent with the broader sustainability agenda will make meeting the objectives more difficult or impossible as ecosystems go beyond tipping points and require a greater level of resource to bring them back to a state of resilience.

Using clearly defined co-production principles and processes could increase the speed of delivery, bringing together a wider set of skills and knowledge from different sectors, institutions and geographical areas. Clearly such action requires significant behavioural change at a personal, local and national level. Awareness of environmental issues has risen recently which provides a timely opportunity to promote and incorporate ways to close the gap between values and action.

Case study: Working with others to develop resilient ecological networks across the UK

NRW is collaborating with other UK country agencies to explore how large-scale ecological networks could be developed as a nature-based solution to solving declines in biodiversity and resilience.

In a changing world, these networks could support a spatial strategy that, together with a collaborative management approach at a local scale, would build environmental and ecological resilience, assist nature and landscape conservation and restore naturally functioning ecosystems. Nature-based solutions at this scale would need to be supported by longer term funding strategies.

The role of Area Statements

NRW has been at the heart of developing a series of innovative Area Statements covering seven separate and diverse parts of the country (NRW, 2020a). These are a collaborative response to the Natural Resources Policy (Welsh Government, 2017) and are an evidence and delivery vehicle for the sustainable management of natural resources.

The Local Biodiversity Action Plans (LBAPs) published by local authorities have been revised to create “local Nature Recovery Action Plans” (NRAP) that reflect the national plan (Welsh Government, 2015). Lessons learned from the working methods trials could be applied nationally to ensure that the creation and implementation of local NRAPs are aligned with their relevant Area Statement, SMNR principles and ways of working in the Well-being of Future Generations Act 2015.

Achieving resilient Welsh ecosystems

Increasing ecosystem resilience is fundamental to sustaining the vital services delivered by natural resources. Wales has much of the regulatory and policy frameworks in place, but we as a society need to raise our ambition and commitment to the next level and act faster, more joined-up, and at a larger spatial scale. Increasing public awareness of the climate and nature emergencies will win further support for transformational systems and behaviour change in order to make sustainability the central organising principle of thriving communities in Wales.

The opportunities identified for action are:

- Develop the assessment of ecosystem resilience
- Build on Wales's policy framework
- Optimised regulation, consistent with SMNR
- Effective ecosystem management
- Build wider engagement

Evidence needs

This report identifies gaps in the evidence needed to assess the sustainability of natural resources. These gaps could be plugged by:

- building a monitoring strategy for Wales that is capable of reporting on aspects of resilience across the whole landscape and which can support transformational management change
- focussing on means of monitoring condition more comprehensively, since condition is a key factor in the current poor resilience, and ensuring that both earth observation technology and ground-based measures are utilised
- assessing whether current species diversity measures are sufficient or need modifying to include particular keystone species for ecosystem function.

Sea or landscape-scale assessment tools could be developed by practitioners if accessible, open-source data was easily available. Some tools could be developed by re-using data previously collected for another purpose.

References

Alison J, Maskell LM, Smart SM, Feeney C, Henrys PA, Botham M, Robinson DA, Emmett BA. 2020. Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report 30: Analysis of National Monitoring Data in Wales for the State of Natural Resources Report 2020. Report to Welsh Government (Contract C210/2016/2017). UK Centre for Ecology & Hydrology Project 06297. Available from: https://erammp.wales/en/gmep-data-analysis [Accessed December 2020]

Beller EE, Spotswood EN, Robinson AH, Anderson MG, Higgs ES, Hobbs RJ, Suding KN, Zavaleta ES, Grenier JL, Grossinger RM. 2019. Building Ecological Resilience in Highly Modified Landscapes. BioScience 69 (1), 80-92.

Bender EA, Case TJ, Gilpin ME. 1984. Perturbation experiments in community ecology: theory and practice. Ecology 65, 1-13.

Chase JM, Blowes S, Knight TM, Gerstner K and May F. 2020. Ecosystem decay exacerbates biodiversity loss with habitat loss. Nature 584, 238-243.

Cole LJ, Stockan J, Helliwell R. 2020. Managing riparian buffer strips to optimise ecosystem services: A review. Agriculture, Ecosystem and Environment 296.

Convention on Biological Diversity (CBD). 1992. Rio Declaration on Environment and Development. The United Nations Conference on Environment and Development.

Crick HQP, Crosher IE, Mainstone CP, Taylor SD, Wharton A, Langford P, Larwood J, Lusardi J, Appleton D, Brotherton PNM, Duffield SJ & Macgregor NA. 2020. Nature Networks: A Summary for Practitioners. Natural England Research Report NERR082. York: Natural England.

Emmett BE, GMEP team. 2017. Glastir Monitoring & Evaluation Programme. Final Report to Welsh Government - Executive Summary (Contract reference: C147/2010/11). NERC/Centre for Ecology & Hydrology (CEH Projects: NEC04780/NEC05371/NEC05782).

Garrett HM. 2020. Quantitative methods for assessing ecosystem resilience. A literature review. Natural Resources Wales Evidence Report No. 446. Dolgellau: NRW.

George PBL, Lallias S, Creer S, Seaton FM, Kenny JG, Eccles RM, Griffiths RI, Lebron I, Emmett BA, Robinson DA, Jones DL. 2019. Divergent national-scale trends of microbial and animal biodiversity revealed across diverse temperate soil ecosystems. Nature Communications 10 (1107).

Harris SJ, Massimino D, Eaton MA, Gillings S, Noble DG, Balmer DE, Pearce-Higgins JW, Woodcock P. 2019. The Breeding Bird Survey 2018. BTO Research Report 717. Thetford: British Trust for Ornithology.

Hayhow DB, Eaton MA, Stanbury AJ, Burns F, Kirby WB, Bailey N, Beckmann B, Bedford J, Boersch-Supan PH, Coomber F, Dennis EB, Dolman SJ, Dunn E, Hall J, Harrower C, Hatfield JH, Hawley J, Haysom K, Hughes J, Johns DG, Mathews F, McQuatters-Gollop A, Noble DG, Outhwaite CL, Pearce-Higgins JW, Pescott OL, Powney GD, Symes N. 2019. The State of Nature 2019. The State of Nature partnership.

Hilty J, Worboys GL, Keeley A, Woodley S, Lausche B, Locke H, Carr M, Pulsford I, Pittock J, White JW, Theobald DM, Levine J, Reuling M, Watson JEM, Ament R, Tabor GM. 2020. Guidelines for conserving connectivity through ecological networks and corridors. Area Guidelines Series No. 30. Gland: IUCN.

HM Government. 2019. Voluntary National Review of progress towards the Sustainable Development Goals. Available from: https://www.gov.uk/government/publications/uks-voluntary-national-review-of-the-sustainable-development-goals [Accessed December 2020]

International Union for Conservation of Nature (IUCN). 2020. Global Standard for Nature-based Solutions. A user-friendly framework for the verification, design and scaling up of NbS. First edition. Gland: IUCN.

Kuussaari M, Bommarco R, Heikkinen RK, Helm A, Krauss J, Lindborg R, Öckinger E, Pärtel M, Pino J, Rodà F, Stefanscu C, Teder T, Zobel M, Steffan-Dewenter I. 2009. Extinction debt: a challenge for biodiversity conservation. Trends in Ecology and Evolution 24 (10), 564-571.

Laffoley DA, Brockington S, Gilliland PM. 2006. Developing the concepts of good environmental status and marine ecosystem objectives: some important considerations. English Nature Research Report 689.

Latham J, Thomas RH, Spode S, Lindenbaum K. 2013. Ecosystem resilience: a discussion paper on the use of the concept for natural Resources Wales. Ecosystem Understanding and Future Management Team, Living Wales Programme 2012-13.

Leclère D, Obersteiner M, Barrett M, Butchart SHM, Chaudhary A, De Palma A, DeClerck FAJ, Di Marco M, Doelman JC, Dürauer M, Freeman R, Harfoot M, Hasegawa T, Hellweg S, Hilbers JP, Hill SLL, Humpenöder F, Jennings N, Krisztin T, Mace GM, Ohashi H, Popp A, Purvis A, Schipper AM, Tabeau A, Valin H, van Meijl H, van Zeist W-J, Visconti P, Alkemade R, Almond R, Bunting G, Burgess ND, Cornell SE, Di Fulvio F, Ferrier S, Fritz S, Fujimori S, Grooten M, Harwood T, Havlík P, Herrero M, Hoskins AJ, Jung M, Kram T, Lotze-Campen H, Matsui T, Meyer C, Nel D, Newbold T, Schmidt-Traub G, Stehfest E, Strassburg BBN, van Vuuren DP, Ware C, Watson JEM, Wu W, Young L. 2020.Bending the curve of terrestrial biodiversity needs an integrated strategy. Nature 585, 551–556.

MacDougall AS, McCann KS, Gellner G, Turkington R. 2013. Diversity loss with persistent human disturbance increases vulnerability to ecosystem collapse. Nature 494, 86-89.

Millennium Ecosystem Assessment. 2005.Ecosystems and human well-being: Synthesis. Washington D.C.: Island Press.

Namoi CMA. 2013. Namoi Catchment Action Plan 2010–2020, 2013 Update. Gunnedah, Namoi Catchment Management Authority.

Natural Resources Wales (NRW). 2016. Tree Cover in Wales' Towns and Cities Understanding canopy cover to better plan and manage our urban trees. Bangor: NRW.

Natural Resources Wales (NRW). 2017. Forest Resilience Guide 1: Improving the structural diversity of Welsh woodlands. Cardiff: NRW.

Natural Resources Wales (NRW). 2018. A new baseline of the area of semi-natural habitat in Wales for Indicator 43. Briefing Note. Cardiff: NRW. Available from: https://naturalresources.wales/evidence-and-data/maps/extent-of-semi-natural-habitat-in-wales-indicator-43/?lang=en [Accessed December 2020]

Natural Resources Wales (NRW). 2020a. Area Statements. Building a healthier environment together. NRW. Cardiff. Available from: https://naturalresources.wales/about-us/area-statements/?lang=en [Accessed December 2020]

Natural Resources Wales. 2020b. Environmental Assessment. NRW. Cardiff. Available from: https://naturalresources.wales/guidance-and-advice/business-sectors/planning-and-development/advice-for-developers/environmental-assessment/?lang=en [Accessed December 2020]

Naumann E-K, Medcalf K. 2020. Current relative value (CuRVe) map atlas for ecosystem resilience in Wales. NRW Evidence Report No: 415. Bangor: Natural Resources Wales.

Oberč BP, Arroyo Schnell A. 2020. Approaches to sustainable agriculture. Exploring the pathways towards the future of farming. Brussels: IUCN EURO. Available from: https://portals.iucn.org/library/node/49054 [Accessed December 2020]

Office of the Deputy Prime Minister. 2005. A Practical Guide to the Strategic Environmental Assessment Directive, Practical guidance on applying European Directive 2001/42/EC "on the assessment of the effects of certain plans and programmes on the environment". London: Office of the Deputy Prime Minister.

Rogan JE, Lacher TE. 2018. Impacts of habitat loss and fragmentation on terrestrial biodiversity. In: Reference Module in Earth Systems and Environmental Sciences. Elsevier.

Steentjes K, Demski C, Seabrook A, Corner A, Pidgeon N. 2020. British Public Perceptions of Climate Risk, Adaptation Options and Resilience (RESiL RISK): Topline findings of a GB survey conducted in October 2019. Cardiff: Cardiff University.

Swift TL, Hannon SJ. 2010. Critical thresholds associated with habitat loss: a review of the concepts, evidence, and applications. Biol Rev Camb Philos Soc 85 (1), 35-53.

Walker B, Salt D. 2012. Resilience practise. Building capacity to absorb disturbance and maintain function. Washington DC: Island Press.

Weigelt A, Weisser WW, Buchmann N, Scherer-Lorenzen M. 2009. Biodiversity for multifunctional grasslands: equal productivity in high-diversity low-input and low-diversity high-input systems. Biogeosciences 6 (8).

Welsh Government. 2015. The Nature Recovery Plan for Wales, Setting the course for 2020 and beyond. Available from: https://gov.wales/nature-recovery-action-plan [Accessed December 2020]

Welsh Government. 2016. Environment (Wales) Act 2016. Section 6. Available from: http://www.legislation.gov.uk/anaw/2016/3/contents/enacted [Accessed December 2020]

Welsh Government. 2017. Natural Resources Policy. Available from: https://gov.wales/natural-resources-policy [Accessed December 2020]

Welsh Government. 2018. Planning Policy Wales. Edition 10. Available from: https://gov.wales/planning-policy-wales [Accessed December 2020]

Welsh Government. 2019a. Wales and the sustainable development goals 2019 Supplementary Report to the United Kingdom of Great Britain and Northern Ireland. Available from: https://gov.wales/uk-voluntary-national-review-welsh-supplementary-report-2019 [Accessed December 2020]

Welsh Government. 2019b.The State of Nature 2019 report: 17% of species in Wales are at risk of extinction [online]. Senedd Research blog. Available from: https://seneddresearch.blog/2019/10/15/the-state-of-nature-2019-report-17-of-species-in-wales-are-at-risk-of-extinction/ [Accessed December 2020]

Welsh Government. 2020a. The Nature Recovery Action Plan 2020 - 2021. Available from: https://gov.wales/nature-recovery-action-plan [Accessed December 2020]

Welsh Government. 2020b. Sustainable farm and land use. July 2020. Our response. Available from: https://gov.wales/revised-proposals-supporting-welsh-farmers-after-brexit [Accessed December 2020]

Woodland Trust and Coed Cymru. 2013. The Pontbren Project. A farmer-led approach to sustainable land management in the uplands. Available from: https://www.woodlandtrust.org.uk/publications/2013/02/pontbren-project-sustainable-uplands-management/ [Accessed December 2020]