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Ecological Connectivity and Biodiversity Prioritisation in the Terrestrial Environment of Wales

J. Latham, J. Sherry & J. Rothwell,
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Terrestrial Ecosystem Group
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Ecological Connectivity and Biodiversity Prioritisation in the Terrestrial Environment of Wales

Jim Latham, Jan Sherry & Jonathan Rothwell
Terrestrial Ecosystems Group, Countryside Council for Wales

Summary

- This report gives a general account of the work on connectivity and priority mapping carried out by Countryside Council for Wales (CCW), and provides a broad introduction for its practical application by Natural Resources Wales (NRW) staff. It consolidates and updates previous work on connectivity by CCW.

- Fragmentation and habitat loss have profound impacts on biodiversity and ecosystems. The report summarises these impacts and introduces the concept of ecological connectivity and approaches to improving it within landscapes.

- Habitat network modelling provides a basis for mapping connectivity. The CCW/Forestry Commission Wales (FCW) forest habitat network project provided the groundwork for this, combining Forest Research's least-cost modelling methodology (with the 'BEETLE' toolkit) with CCW's Phase 1 habitat survey. The work has been extended and refined with CCW's Network Tool.

- The output of the model is a series of mapping layers, known as core, focal and local networks. Together these provide a guide to overall habitat connectivity and can be interpreted in various ways to inform biodiversity action and environmental projects in general.

- Mapping is available for broadleaved woodland, heathland, unimproved grassland, fens and bogs, each (except woodland) in upland and lowland versions. Mapping for a wide number of other habitats is under development or planned; mapping can also be carried out for individual species. Example maps for the main habitat groups are provided at all-Wales level.

- The network maps can be used to help understand the significance of habitat patches in the landscape and the functional relationships between them. As such, they provide a general guide to the location of habitat restoration and expansion.

- The network maps have many potential applications, including: natural resource planning, spatial planning (e.g. Local and Rural Development Plans), ecosystem services mapping, agri-environment targeting, access plans, economic development policies, green infrastructure plans, National Park and AONB Management Plans, site notification programme, biodiversity

offsetting and habitat banking, landscape-scale restoration projects e.g. LIFE and Heritage Lottery Fund, Local Biodiversity Action Plans (LBAP).

- However, the network maps also need to be used with caution, and their limitations should be recognised. They require interpretation and **do not** provide specific prescriptions of where to develop new habitats and ecosystems.

- The network maps are being used as the basis for Priority Mapping to help guide limited resources to locations of most benefit. This uses a system of three priority mapping levels: Level 1 – maps of the whole habitat resource and connectivity around them; Level 2 – maps of key networks that contain the most significant examples of habitat; Level 3 – maps of specific locations requiring urgent action.

- Natural Resources Wales is applying an ecosystem approach to its work, and the network maps should make an important contribution to this. Examples include i) guidance on conifer plantation management restructuring to maintain productivity whilst benefiting heathland ecosystem connectivity and enhancing recreational opportunities; and ii) targeting woodland expansion to benefit both woodland ecosystem resilience and flood management.

- The work described in this report should prove useful in many areas of work for NRW, Welsh Government and partners. However, the mapping shouldn't be seen as static and will need to adapt as understanding of ecosystems improves, datasets are refined and technology advances. Continued support, research and development will be required to do this.

Cysylltedd Ecolegol a Blaenoriaethu Bioamrywiaeth yn Amgylchedd Daearol Cymru

Jim Latham, Jan Sherry a Jonathan Rothwell
Grŵp Ecosystemau Daearol, Cyngor Cefn Gwlad Cymru

Crynodeb

- Mae'r adroddiad hwn yn rhoi disgrifiad cyffredinol o'r gwaith mapio blaenoriaethau a chysylltedd a wnaed gan Gyngor Cefn Gwlad Cymru, ac mae'n rhoi cyflwyniad eang i staff Cyfoeth Naturiol Cymru allu defnyddio hynny'n ymarferol. Mae'n cyfuno ac yn diweddaru gwaith blaenorol ar gysylltedd a wnaed gan Gyngor Cefn Gwlad Cymru.

- Mae darnio a cholli cynefinoedd yn cael effaith sylweddol iawn ar fioamrywiaeth ac ecosystemau. Mae'r adroddiad yn crynhoi'r effeithiau hyn ac yn cyflwyno'r cysyniad o gysylltedd ecolegol a dulliau ar gyfer gwella hynny mewn tirweddau.

- Mae modelu rhwydweithiau cynefinoedd yn sail ar gyfer mapio cysylltedd. Darparodd prosiect rhwydweithiau cynefinoedd coedwigoedd Cyngor Cefn Gwlad Cymru/Comisiwn Coedwigaeth Cymru'r sail ar gyfer hyn, gan gyfuno methodoleg modelu cost isaf Forest Research (gyda'r pecyn cymorth 'BEETLE') ag arolwg cynefinoedd Cam 1 Cyngor Cefn Gwlad Cymru. Mae'r gwaith wedi'i ymestyn a'i addasu gydag Offeryn Rhwydwaith Cynefinoedd Cyngor Cefn Gwlad Cymru.

- Allbwn y model yw cyfres o haenau mapio, a elwir yn rhwydweithiau craidd, canolog a lleol. Gyda'i gilydd, mae'r rhain yn darparu arweiniad i gysylltedd cynefinoedd yn gyffredinol, ac mae modd eu dehongli mewn gwahanol ffyrdd i fod yn sail i gamau gweithredu bioamrywiaeth a phrosiectau amgylcheddol yn gyffredinol.

- Mae mapio ar gael ar gyfer coetir llydanddail, rhostir, glaswelltir heb ei wella, ffeniau a mignenni a chorsydd, ym mhob un (ac eithrio coetir) mewn fersiwn ucheldir ac iseldir. Mae gwaith mapio ar gyfer nifer fawr o gynefinoedd eraill yn cael ei ddatblygu neu ei gynllunio; mae modd mapio rhywogaethau unigol hefyd. Mae mapiau enghreifftiol ar gyfer y prif grwpiau cynefinoedd ar gael ar lefel Cymru gyfan.

- Mae modd defnyddio'r mapiau rhwydwaith i helpu i ddeall arwyddocâd lleiniau o gynefinoedd yn y dirwedd a'r berthynas ymarferol rhyngddynt. Felly, maent yn ganllaw cyffredinol i leoliadau adfer ac ymestyn cynefinoedd.

- Mae sawl defnydd posib i'r mapiau rhwydwaith, gan gynnwys: cynllunio adnoddau naturiol, cynllunio gofodol (Cynllun Datblygu Lleol, Cynllun

Datblygu Gwledig), mapio gwasanaethau ecosystemau, targedu amaeth-amgylcheddol, cynlluniau mynediad, polisïau datblygu economaidd, cynlluniau seilwaith gwyrdd, Cynlluniau Rheoli Parciau Cenedlaethol ac Ardaloedd o Harddwch Naturiol Eithriadol, rhaglen hysbysu safle, gwrthbwyso bioamrywiaeth a bancio cynefinoedd, prosiectau adfer ar raddfa tirwedd e.e. LIFE a Chronfa Dreftadaeth y Loteri, Cynlluniau Gweithredu Bioamrywiaeth Lleol.

- Fodd bynnag, mae gofyn bod yn ofalus wrth ddefnyddio’r mapiau rhwydwaith hefyd, a dylid cydnabod eu cyfyngiadau. Mae gofyn eu dehongli ac **nid ydynt** yn darparu rhagolygon penodol o ble i ddatblygu cynefinoedd ac ecosystemau newydd.

- Mae’r mapiau rhwydwaith yn cael eu defnyddio fel sail ar gyfer Mapio Blaenoriaethau i helpu i arwain adnoddau prin i’r lleoliadau sydd o fwyaf o fudd. Defnyddir system o dair lefel mapio blaenoriaethau: Lefel – mapiau o’r adnoddau cynefin cyfan a’r cysylltedd o’u hamgylch; Lefel 2 - mapiau o'r rhwydweithiau allweddol sy'n cynnwys yr enghreifftiau mwyaf arwyddocaol o gynefinoedd; Lefel 3 – mapiau o leoliadau penodol ble mae angen gweithredu ar unwaith.

- Mae Cyfoeth Naturiol Cymru yn defnyddio dull ecosystem yn ei waith, a dylai’r mapiau rhwydwaith wneud cyfraniad pwysig i hyn. Mae enghreifftiau’n cynnwys i) arweiniad ar ailstrwythuro’r broses o reoli planhigfeydd conwydd i gynnal cynhyrchiant a bod o fudd i gysylltedd ecosystemau rhostir a gwella cyfleoedd hamdden; a ii) targedu ehangu coetiroedd i fod o fudd i wytnwch ecosystemau coetiroedd a rheoli llifogydd.

- Dylai’r gwaith a ddisgrifir yn yr adroddiad hwn fod yn ddefnyddiol mewn sawl maes gwaith ar gyfer Cyfoeth Naturiol Cymru, Llywodraeth Cymru a phartneriaid. Fodd bynnag, ni ddylid gweld y mapio fel rhywbeth statig a bydd gofyn addasu wrth i’n dealltwriaeth o ecosystemau wella, wrth i setiau data gael eu haddasu ac wrth i dechnoleg ddatblygu. Bydd cefnogaeth, ymchwil a gwaith datblygu parhaus yn ofynnol i wneud hyn.

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1.0 Introduction

This report provides an overview of the work of the Countryside Council for Wales (CCW) on habitat network mapping and its applications for understanding ecological connectivity, targeting action for biodiversity, and informing ecosystem-level projects. It builds upon CCW's earlier work on ecological connectivity (Latham, 2007a, 2007b; Latham *et al*., 2008) and is intended as a broad introduction for the staff of Nature Resources Wales (NRW) and partners, and as a guide to practical application of connectivity mapping. We hope it will also form a basis for NRW to continue to support research and development in this field

The original stimulus for this work was the proliferation, in recent years, of landscape-scale projects that use mapped habitat and connectivity data. Habitat specialists within CCW were regularly asked to supply mapped data, but it was clear that there was often confusion from practitioners over what data were available, their origin and how they could be used. To address this, in early 2010 CCW initiated a project to develop a consistent 'integrated package of maps and guidance' for users.

The proposal was taken up with enthusiasm by Wales Biodiversity Partnership (WBP), which was keen that the guidance should include mapped strategic priorities for conservation action to help target ever diminishing resources.

The work was clearly also relevant to the newly emerging Natural Environment Framework (Welsh Assembly Government, 2010), as it could provide maps of the current locations of ecosystems, and had the potential to identify where ecosystems should be expanded or restored to benefit both biodiversity and other ecosystem services. Under the umbrella of the Natural Environment Framework, a number of local authority initiatives focusing on strategic planning for natural resources began incorporating a range of connectivity and biodiversity mapping data. This reinforced the need for a consistent approach across Wales.

The Natural Environment Framework led in turn to the "Sustaining a Living Wales" consultation (Welsh Government, 2012) and the reorganisation of the three environmental organisations in Wales - CCW, Forestry Commission and the Environment Agency - into a single body, Natural Resources Wales, scheduled for April 2013.

Adoption of the Ecosystem Approach has been identified as fundamental to the delivery of a more integrated approach to the environment within Natural Resources Wales (NRW). The Ecosystem Understanding and Future Management Team within Welsh Government's Living Wales Programme has been developing guidance on the Ecosystem Approach and Ecosystem Resilience for NRW (Spode *et al*., 2013; Latham *et al*., 2013). Biodiversity connectivity mapping is seen as an integral part of this work (Thomas *et al*., 2013).

Despite the changing landscape for environmental delivery in Wales the original aim of providing an integrated package of maps and guidance is still considered relevant and necessary. However the maps and guidance need to be multifunctional to ensure they are pertinent to the new policy approaches being adopted by Welsh Government and Natural Resources Wales.

2.0 Rationale for Ecological Connectivity Mapping

2.1 Effects of Habitat Loss and Fragmentation

Many of the major issues affecting ecosystem functioning and biodiversity conservation result from the loss and fragmentation of natural habitats. Habitat loss and fragmentation have gone on for thousands of years as natural habitats have been cultivated and modified, or replaced by artificial systems and the built environment. However, many serious losses have occurred only relatively recently. For example, between 1930 and 1980 an estimated 9% of the ancient semi-natural woodland in Wales was cleared, and a further 42% converted to plantation (Spencer & Kirby, 1992). More extreme is the astonishing 97% loss of lowland semi-natural grasslands in England and Wales in the 20th century (Fuller, 1987, described in Blackstock *et al*., 2010). Nature conservation legislation and greater public awareness have reduced the rates of decline, but losses still continue, especially loss of smaller patches of habitat that slip below levels required for protection.

These changes have profound impacts on biodiversity and ecosystems in general. These can be classified into effects of area loss, isolation and edge effects (Watts *et al*., 2005a), although each of these also interact. Taking each in turn:

- Area loss can cause populations of organisms to decline or become extinct because the patches of habitat in which they live may simply become too small to have the resources required to sustain them. A smaller patch of habitat will also support fewer individuals, making their population more vulnerable to decline or extinction through chance events; they may also have lower genetic diversity and capacity to adapt to change.

- Isolation can be the result of increased distance between patches, or deleterious changes in the condition – or permeability - of the habitats between them. Either way, the effect is to reduce the ability of organisms to move between habitat patches and around the landscape. This can affect many processes across different spatial and temporal scales, including: foraging, roosting, dispersal, migration, pollination, colonisation to maintain metapopulations, breeding behaviour, genetic exchange, and ability to adjust population range in response to climate change.

- Edge effects are damaging external influences. These increase with fragmentation, because as patches become smaller and their edge to area ratio increases, a higher proportion of habitat becomes exposed to external influences. These influences are diverse, and may include nutrient input (i.e. eutrophication), pollution, pesticide and herbicide drift, noise disturbance, drainage (e.g. through local lowering of water tables), changes in light levels, physical abuse (e.g. trampling or tipping), changes in air currents, changes in moisture regime, increased climatic stress, increased risk of disease, and colonisation by invasive species.

The result of all these effects is to reduce the fitness of organisms and their populations, making them more vulnerable to extinction, either locally or globally Climate change is an over-riding factor, interacting with all of the above and produces an additional stress. (See Hopkins (2013) for an accessible review and examples of impacts.)

In addition to the effects of fragmentation on individual species, the broader impacts on ecosystems need to be considered. Fragmentation can have serious impacts on a wide range of ecosystem functions and services, including nutrient cycling, water quality and management, carbon sequestration, air quality and pollination.

2.2 The Principles of 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; Box 1). Latham *et al*. (2008) provide more background and discussion on approaches to connectivity in Wales.

Box 1.

"Movement in nature can take many forms: soil, fire, wind, and water move; plants and animals move; ecological interactions, ecosystem processes, and natural disturbances move, or elements move through them. All require, to different degrees and at different scales, connectivity in nature."

Crooks & Sanjayan, from the introductory chapter of their book, *Connectivity Conservation.* (Crooks & Sanjayan, 2006).

In simple terms, connectivity can be thought of as the inverse of fragmentation, and actions to reverse or mitigate the effects of fragmentation will improve connectivity. However, there is more to it than that, and it is not simply about physical connectedness and 'joining things up'. To its detriment, connectivity is often thought of in this way, and equated with features such as linear corridors and dormice bridges. Whilst these features have a place, they are only part of a wide array of approaches that can improve connectivity, from management of individual sites to regional land-use strategies. Good management of habitat patches is an important first step, as it can increase the size and fitness of populations, making species more able and likely to move.

Actions may also work by improving the permeability of the land between habitat patches, thus allowing *functional* connectivity to be enhanced. Some actions to improve connectivity include:

- Improving site condition through good management to improve *within-patch* connectivity and fitness of populations;
- Increasing habitat patch size;

- Developing buffers around patches;
- Expanding habitat to join patches;
- Developing stepping stones between patches;
- Developing corridors;
- Improving the condition of land between habitat patches to increase permeability;
- Improving the extent and condition of landscape features such as hedgerows, field-margins and water courses;
- Developing networks of habitats;
- Encouraging large continuous areas of habitat at a landscape-scale.

A common theme of these actions is that they require thinking beyond individual sites, and consider the wider landscape and the interactions of its components. As such, they fit closely with developing approaches to environmental management, such as the Ecosystem Approach, and require what are often talked about as 'landscape-scale approaches'.

3.0 Overview of Connectivity Modelling

3.1 Background to Landscape-scale Approaches

The need for large scale approaches to address the problems of habitat loss and fragmentation has been recognised for decades. However, for a long while there was neither the political support nor resources required to take these actions very far. Most nature conservation resources were used addressing urgent, individual losses, rather than on broader landscape aspirations. Political recognition of the need for large-scale approaches steadily increased, and in the 1990s there was a great deal of discussion around the subject, notably stimulated by the Convention on Biological Diversity, opened at the Rio de Janeiro Earth Summit in 1992. The UK Biodiversity Action Plan was a bold attempt to put these ideals into practice, and contained not only targets for maintenance of habitats and species populations, but also references to ecological networks and targets for habitat expansion, typically by a pragmatic 10% of the existing resource.

Forest ecologists have often lead the thinking on landscape-scale approaches, probably because woodland and forests are widely accepted as landscape-scale formations, with a coarse 'ecological grain' suitable for such discussion. Peterken *et al*. (1995) set out pioneering plans for a national woodland network in Scotland, which generated much interest throughout the UK. A flavour of the thinking on large-scale approaches about this time was captured in a conference convened by Forestry Commission in 2000 to bring together researchers, practitioners and policymakers working on woodland restoration (Humphrey, *et al*. 2003). Technical advances have greatly aided the development of large-scale approaches in the last decades, and in particular the evolution and greatly increased availability of Geographic Information Systems (GIS).

3.2 The Forest Habitat Network Project in Wales

Against this background, CCW and Forestry Commission Wales (FCW) formed a keen interest in developing a strategic map of woodland and forest networks in Wales. The aim was to identify existing, functional networks of woodland and forest to help target conservation action and new woodland establishment so that truly robust, landscape-scale woodland networks could be developed. The preliminary approach was simply to sit down with maps and some experienced individuals in the hope of identifying pragmatic groupings of woodlands as networks, but this was quickly realised to be naïve. There were too many questions and unknowns: how much woodland is needed within an area to constitute a network? How close must woods be to be considered linked? How can habitats and different land-uses between woods be taken into account? What scale should networks be considered at? Many of these issues arose from a growing recognition that networks do not necessarily comprise simple physical links, but also ‘functional links’ of intervening habitat.

In response, in 2003 CCW and FCW secured funding for a research project to develop the theory, and to formally model and map habitat networks in Wales. The contract was awarded to Forest Research (FR), and overseen by a steering group made up of representatives from CCW, FCW, Woodland Trust, and independent expert Dr George Peterken. The project had several stages: to review the literature on fragmentation and network theory, to explore landscape metrics and concepts such as thresholds of forest cover, to develop an appropriate modelling methodology, and to produce indicative maps of forest habitat networks in Wales (Latham *et al*., 2004; Watts *et al*. 2005; Latham, 2006). An important early finding was that woodland in Wales is strongly clumped in distribution and highly dependent on landform, and no simple rules or thresholds can be universally applied to map or help develop networks. A modelling approach was proposed that could flexibly take into account the size and distribution of habitat patches, and, importantly, the contribution of the habitats between them. The work was seminal in that it linked FR’s burgeoning least-cost modelling methodology (popularly known as ‘BEETLE’) with CCW’s Phase 1 habitat survey (Howe, *et al*. 2005), thus for the first time mapping forest habitat networks that considered the contribution of non-woodland habitats, and at a comprehensive national scale. Later stages of the project considered networks for non-woodland habitats, producing preliminary maps for heathland, bogs, fens, and a variety of grassland types (Eycott *et al*., 2007a).

Box 2. A quick explanation of the habitat network maps

The basic output of the model are 'habitat network maps'. These can be thought of simply as 'buffers' around habitat patches, which indicate the area within which many species typical of that habitat are likely to be able to move. However, they are 'intelligent' buffers, in that they vary in width to take into account the relative ease of movement of through the different surrounding habitats. Where buffers from more than one habitat patch overlap, the patches are said to form a habitat network. This network gives a general picture of likely habitat connectivity in the landscape.

3. 3 Habitat Network Modelling

The modelling is described in Watts *et al*. (2005a), with more detailed information on the methodology and underlying theory available in Watts *et al*. (2005b), Watts *et al*. (2007), Watts *et al*. (2010) and Eycott & Watts (2011). Box 2 gives a simple way of summarising the work, and Box 3 gives a summary of its 'ingredients'. The model has a species basis, and in essence it attempts to predict the area around a given habitat within which a species may move. However, selecting species for the analysis is problematic, as there is often relatively little good information to include within the model, and it is also hard to get consensus over which species to use. The approach usually taken therefore, is to employ an artificial 'focal species', with movement characteristics assigned through expert opinion to be representative of a broad group of taxa, for example 'woodland specialists'. This may sound 'dodgy', but the approach can be powerful for exploring the practical extent and scope of different network parameters. Specifically, it can be used to predict the likely minimum and maximum extents of networks – or 'bookends' – that are likely to reflect the use of the landscape by a broad sweep of biodiversity, and hence provide pragmatic maps for practical application. The standard approach is to model the networks at two complementary levels. These are:

1) **Core networks**, modelled for focal species requiring relatively large areas of habitat but which have poor powers of dispersal.

2) **Focal networks**, modelled for focal species requiring only small areas of habitat and that have moderately good powers of dispersal.

The strength of this approach is that it identifies the upper and lower limits of networks that are likely to have *practical application* to benefit biodiversity. Species that require larger habitat patches and disperse more poorly than the focal species for which the core networks have been modelled are unlikely to benefit much in their survival from any kind of network development and some other action such as *in situ* protection or translocation may be a more relevant approach. Conversely, species that require smaller patches of habitat and disperse more freely than the focal species used to model the focal networks are unlikely to need networks in the first place. It is species who's movement characteristics fall between the core and focal networks that are likely to benefit most from network development.

Box 3. What goes into the network model?

The model requires the following elements:

- A species of interest (usually a generic species profile)
- A specified home habitat (e.g. ‘woodland’)
- A figure for the minimum viable area of home habitat
- A figure for the maximum movement, or dispersal distance of the species within its home habitat
- A habitat map
- Ecological costs assigned to each habitat present
- A cost surface comprising the habitat map and ecological costs.

3.4 Least-cost Modelling

Least-cost modelling was used to map habitat networks. The term ‘cost’ relates to the ecological cost of movement in the landscape (it is nothing whatever to do with economic cost – a common misunderstanding), and can be thought of as the inverse of ‘permeability’.

In the model, all habitats are assigned an ecological cost, depending on their perceived similarity to the ‘home’ habitat being modelled, and hence relative movement ability. This requires an underlying map, and CCW’s digitised Phase 1 habitat survey was used (Howe *et al*., 2005). Costs were assigned by expert opinion, which in the original FR research was the project steering group. Each habitat recorded in Phase 1 was assigned a cost on a range from 1 (home habitat, e.g. broadleaved woodland), to 50 (very high cost, hostile habitat, e.g. roads). The assignment considered two factors i) the degree of modification (e.g. hay meadow is lower cost than improved grassland as it is more likely to allow woodland species to move across it or persist for some time within it) and ii) structural complexity (e.g. bracken and scrub are lower cost than grassland as they have a structure more akin to woodland). The costs for all habitats were assembled in a table, which was then combined with the underlying habitat maps to generate a ‘cost surface’ used by the model.

The focal species is assigned a maximum movement distance that it is considered to be able to move within its own, home habitat. The algorithm considers each cell (i.e. the minimum mapped unit within the digital map, usually a square of 10x10m) of home habitat on the cost surface, and calculates the movement of the focal species away from it in all directions through each adjacent cell; the distance it will ‘move’ depends upon the cost of the habitat it moves through. Thus if a focal species has been assigned a maximum movement distance of 1,000m within its home habitat, and the cost of an adjacent habitat has been given as 10, it will be able to move a maximum of 1/10 x 1,000 = 100m across the adjacent habitat. Different habitats can have different costs and their effects can be cumulative up to the equivalent of its maximum distance assigned for its home habitat. For example, if this focal species encounters a 50m band of a habitat of cost 10, it can cross it and 'use up' an equivalent of 500m (i.e. 10x50 = 500m), leaving a remaining possible onward movement of up to 500m; this would allow it, say, to move a further 250m across a habitat of cost 2 (500m remaining/2 = 250m), or 10m across a habitat of cost 50 (500m remaining/50 = 10m). These maximum movement distances when mapped give an envelope of potential movement around each patch of home habitat and, where these envelopes overlap, the patches are considered to form a **network**.

Minimum habitat areas and dispersal distances for the core and focal networks were set by Forest Research and the steering group based on their expert knowledge of woodland ecology. These were 10ha and 2ha, and 1km and 5km respectively. The power of this modelling approach is that is capable of summarising huge amounts of complex spatial data and hence the relationships between habitat patches, based on quite simple but arguably robust assumptions on the *relative* suitability of different habitats to a given species. The whole of Wales can be modelled to a resolution of 5m in a single run.

Since the Forest Habitat Network project in Wales, the methodology has become well established in the UK. For example, Forestry Commission's projects to map ancient woodland networks in southwest England. Scotland has embraced the concept (e.g. Moseley *et al*., 2008), and much information is available on modelling and habitat networks through Scottish Natural Heritage's website. Research continues into application of habitat networks to biodiversity conservation, e.g. Oliver *et al*. (2013) explore the role of networks within a broad framework of actions of adaptation to climate change.

4.0 CCW Connectivity Modelling

4.1 The CCW Network Tool

The original Forest Research modelling work was quite influential in Wales, being used in various projects and schemes e.g. Better Woodlands for Wales (Forestry Commission Wales, 2006); Southeast Wales Econet (Gillespie *et al*., 2009; Latham & Gillespie, 2009). However, the mapped outputs were static and could not be refined without engaging Forest Research to re-run the model. Consequently, in 2010 CCW commissioned the *Network Tool* from Forest Research. This is a dedicated programme running in ArcGIS version 9.3.1 (ArcMap) with the 'Spatial Analyst' extension included, which allows the network model to be re-run with full control of the cost surface, dispersal distance, and minimum home habitat area and cell resolution.

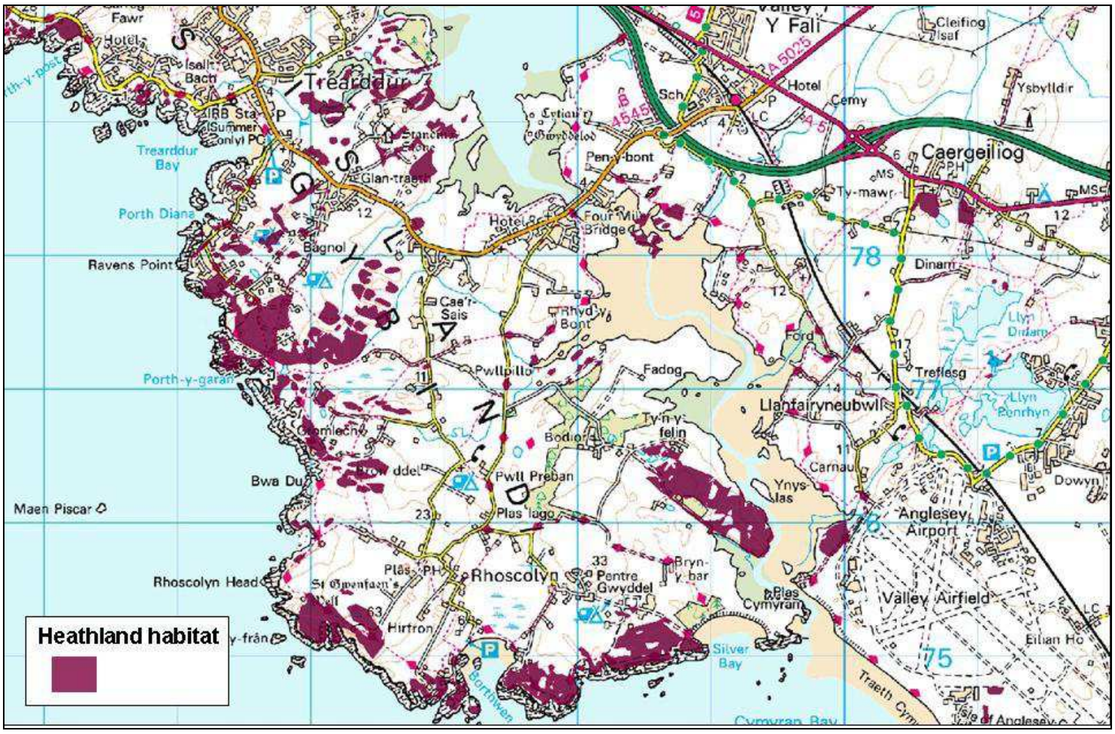
The Spatial Analyst extension is a key component of the GIS setup as the network modelling tool interfaces directly with functions contained within this and cannot be run without it. In addition, the tool also requires the specific version of ArcGIS mentioned above. To complement the GIS software, two dedicated laptops were purchased, both with powerful processing capabilities, plenty of RAM (memory) and

large hard disks capable of storing multiple GIS layers which contain many thousands of polygons.
The resulting large file-sizes for the output layers are due to the complexity of the underlying GIS dataset used in the calculations, the Phase 1 'Habitat Survey of Wales' which comprises 500,000+ polygons, which during the modelling process are converted to outputs at a resolution of 10m pixels. Taking into account the size of the base-datasets and the computationally intensive calculations performed when creating the models, the availability of appropriate hardware was critical as it was necessary to produce multiple iterations of the networks quickly in order to aid project delivery.

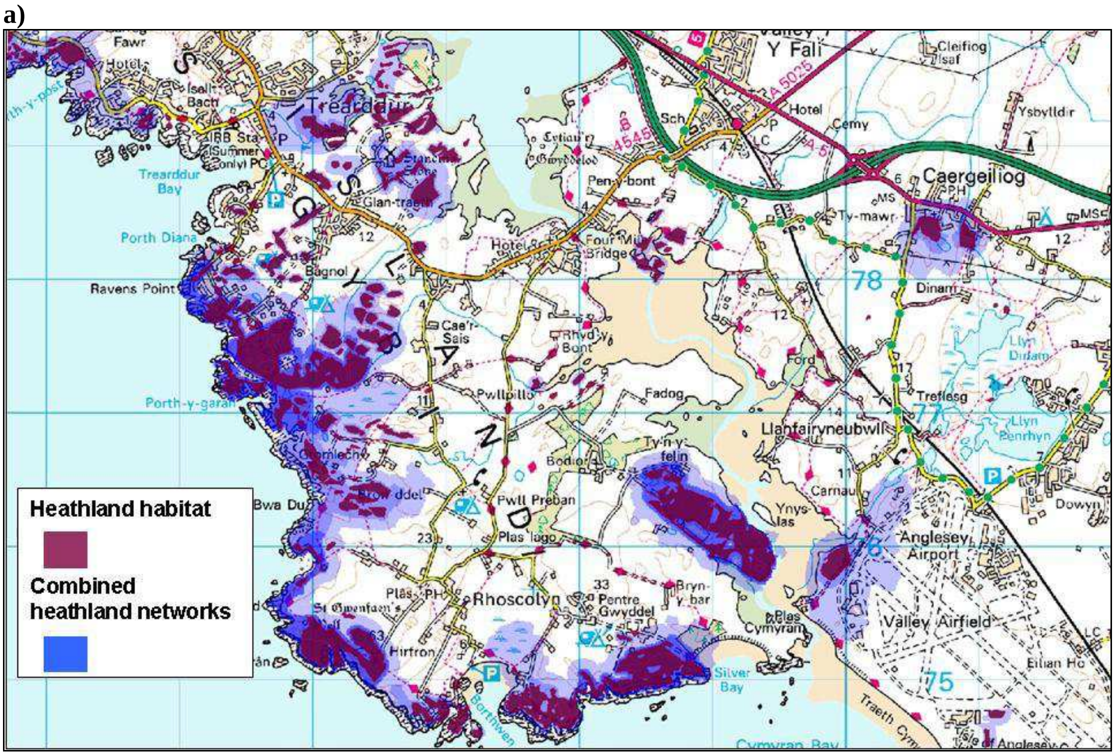
The Network Tool has allowed us to map networks for a variety of habitats (woodland, grassland, heathland, fens, bogs etc.) and to explore a wide range of parameter values to identify the most useful set of networks to inform biodiversity action and wider landscape approaches to the environment. We have retained the concept of **core** and **focal** networks, but added a third type of basic network to address a gap in representation that had become apparent for species that can survive in small blocks of habitat, and have only limited powers of dispersal. We have termed these **local** networks. For these, the minimum habitat area is set very low (sometimes a nominal $1m^2$) to include all mapped habitat but exclude micro-artefacts, and varies depending on the habitat involved and the way small areas have been mapped. A further refinement has been to model habitat networks in lowland and upland versions. Many semi-natural habitats in Wales are disproportionately found in the uplands, and in all-Wales mapping these would sometimes have excessive influence on lowland networks. The classification into upland and lowland habitat was made using the Phase 1 upland boundary, which is based on the upper limit of agricultural enclosure, typically around 300m altitude. Figures 1 and 2 give examples of habitat network maps and illustrate the differences between core, focal and local networks.

If networks for more than one habitat type are mapped together they will be seen to overlap in places. This at first may seem to be a mapping error, or to indicate a conflict of interests. In fact it is usually neither of these – semi-natural habitats contribute to each other's networks, and the overlap may actually indicate that the area of land contains a valuable combination of habitats that provide functional support for a broad spectrum of biodiversity and ecosystems. High overlaps of networks are seen in areas such as parts of the coastal zone and the ffridd – areas that have very high value in terms of ecosystem function, and yet which may not be obviously important when their habitats are considered individually (see Figure 12).

The maps of habitat extent combined with maps of the networks around them gives a starting point to map functional *ecosystems*, rather than simply the separate blocks of habitats that make them up. The approach could be extended to include aspects such as hydrology, to give a more thorough representation of ecosystems and their functions.



a)



b)

Figure 1. An example of habitat networks mapped using the CCW *Network Tool*, for heathland, western Anglesey. 1a) shows heathland habitat patches, appearing as disconnected 'islands' in the landscape; 1b) shows heathland habitat patches within their modelled habitat networks, and gives an indication of the extent of functional connectivity between patches. The networks shown here are a combination of three different sorts, which are explained further in Figure 2.

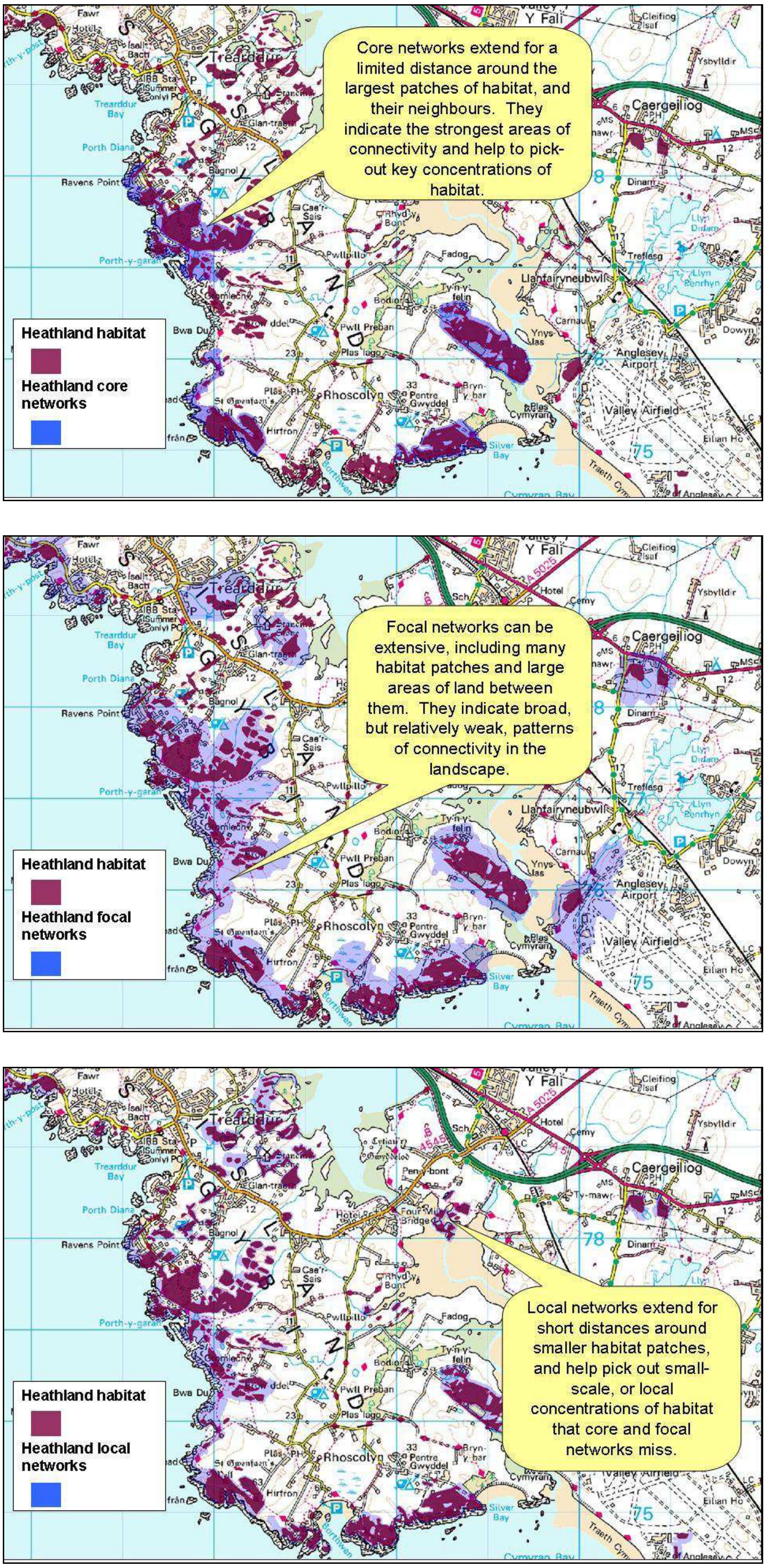


Figure 2. The three types of networks: core, focal and local. Together, these describe complementary aspects of connectivity.

4.2 Habitat Network Outputs

The habitat maps are available as a set of GIS layers, arranged into folders by habitat with upland and lowland versions for each. They are currently held on CCW's server in MapInfo format, and will be made available to all NRW staff when a suitable GIS system has been organised. In time, ideally the maps should be made available publicly via a website, though at this stage it is not clear how this can be done or where the responsibility for it will lie.

If the standard four layers provided are loaded onto GIS they show:

1. The home habitat, i.e. the actual mapped extent of a given habitat.
2. Core networks – the areas of strongest connectivity, and the maximum extent that species most sensitive to fragmentation may be able to regularly move in outside their home habitat.
3. Focal networks – extensive areas of general connectivity, through which species that are moderately sensitive to fragmentation may be able to move.
4. Local networks – very limited areas of connectivity around every habitat patch, that some species can use effectively; in some situations substantial networks can arise from concentrations of very small habitat patches.

4.3 Network Maps for Different Habitats

The CCW Network Tool allows networks to be mapped for whichever habitats underlying data is available (i.e. an underlying habitat map, and data or expert opinion on area and dispersal parameters). As the model works at a species level it can also be applied to individual species, although in Wales relative little work has been done yet (two exceptions are Watts (2009) working on southern damselfly *Coenagrion mercuriale* and Eycott *et al*. (2007b) on great crested newt *Triturus cristatus*). The networks can be re-modelled as new information becomes available, or to address specific projects, such as the impact of removal or addition of habitat in the landscape.

Habitat	Comments
Broadleaved woodland	Original (2005) versions from Forest Research project widely disseminated; refined versions with some mapping fixes produced in 2012.
Heathland (lowland)	In each case, these habitats have been split between upland and lowland networks, but can be mapped together to show the overall resource. These maps supersede early versions by Forest Research (2007).
Heathland (upland)	
Unimproved grassland (lowland)	
Unimproved grassland (upland)	
Fens (lowland)	
Fens (upland)	
Bogs (lowland)	
Bogs (upland)	

Table 1. Habitat network maps that are available for release, March 2013

So far we have concentrated on producing a set of network maps for the main terrestrial habitat groups that can be used in general analyses, as well as exploring the possibilities for minor or more specialised habitats. Networks maps openly available at the time of writing (March 2013) are summarised in Table 1, and those in draft and future possibilities in Table 2. Figures 3 - 12 give examples of the mapping for main habitat groups at an all-Wales level.

Habitat	Comments
Conifer woodland	Draft network maps produced, 2011.
All woodland habitats (conifer, mixed, broadleaved)	Potentially a useful layer and easy to generate.
Broadleaved woodland with reduced-cost conifers	Draft maps produced 2011. Shows the additional broadleaved woodland network areas that could be achieved through increased permeability of conifer woodland (e.g. through LISS, increased broadleaved component). Has potential to inform strategic management of conifer resource.
Ancient woodland	Would include PAWS as habitat, and so has potential as strategic guide to restoration. FR produced a version 2005, but needs re-modelling with revised AWI.
Heathland with reduced-cost conifers	Draft maps produced 2011. Shows the additional heathland network areas that could be achieved through increased permeability of conifer woodland (e.g. through increased open space, suitable harvest rotation and spatial arrangement). Has potential to inform strategic management of conifer resource.
Bogs with reduced-cost conifers	Draft maps produced 2011. Shows the additional bog network areas that could be achieved through increased permeability of conifer woodland (e.g. through increased open space). Requires incorporation of maps of peat soils. Has potential to inform strategic management of conifer resource.
Marshy grassland	Draft maps produced in 2011 and early versions done by FR (2005). Require some refinement but potentially useful layer.
Calcareous grassland	Early attempts by FR (2005) but require revision with increased expert opinion of costs.
Freshwater and wetland habitats	Some trials carried out of combined freshwater and wetland habitats. Potentially a very useful map layer.
Sand dunes	Draft maps produced in 2011; require revision with expert input to cost layer.
Orchards	Draft maps produced in 2012 to help identify key orchard concentrations.
Arable	Discussions to model arable networks based Phase 1 and historic occurrence to help identify restoration areas.
Hedgerows	Future inclusion in woodland networks based on data from remote sensing project
Ancient and veteran trees	Potential through Woodland Trust Ancient Tree Hunt and linked to key dependant species
Cliffs and scree	Not appropriate - highly dependant on geology and localised geomorphological features
Montane	Very scarce and scattered networks not appropriate

Table 2. Examples of habitat networks under development or identified as potentially of strategic value.

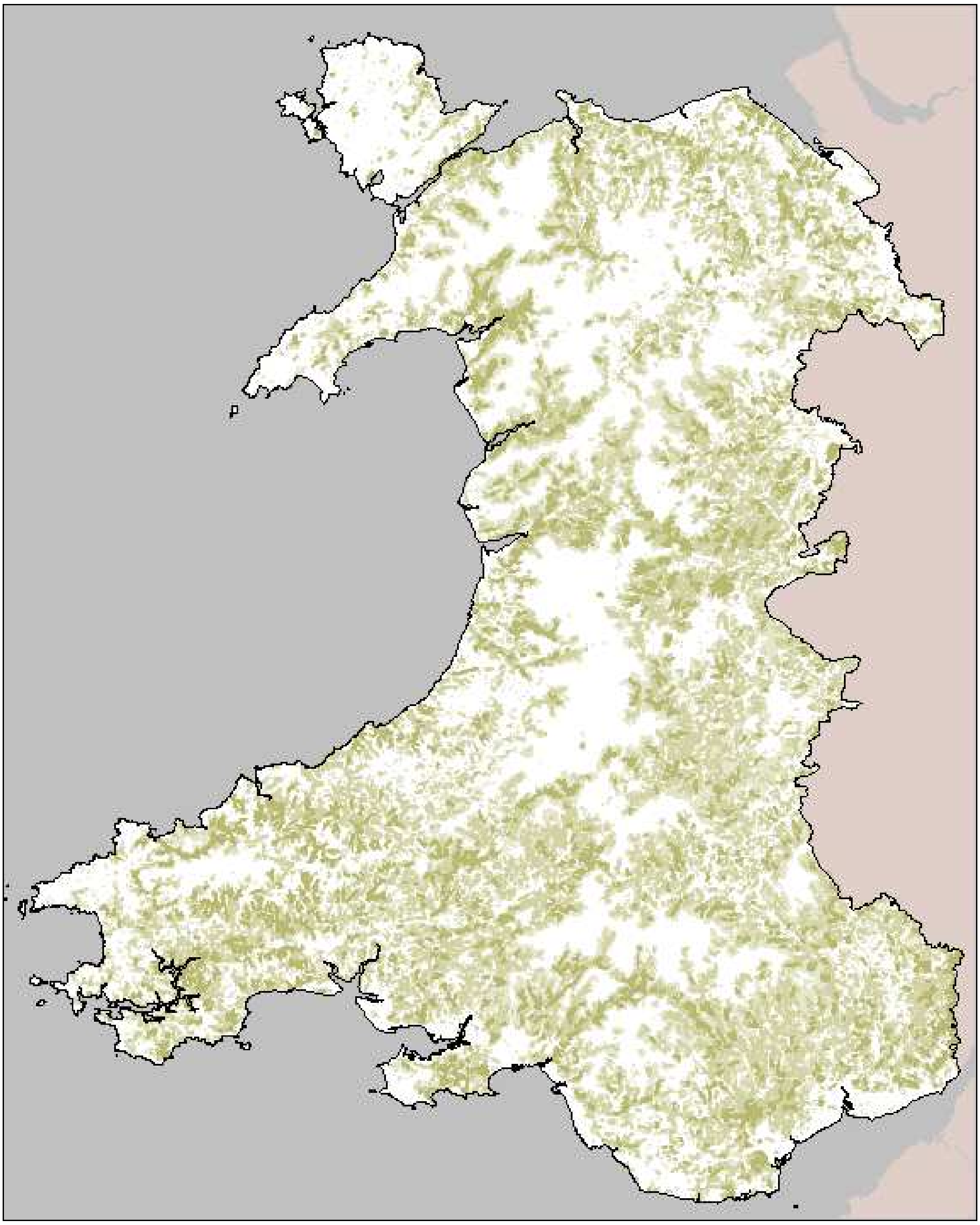


Figure 3. Broadleaved woodland habitat networks in Wales. Core, focal and local networks have been superimposed, and the depth of colour indicates the strength of ecological connectivity for this habitat. See text for details.

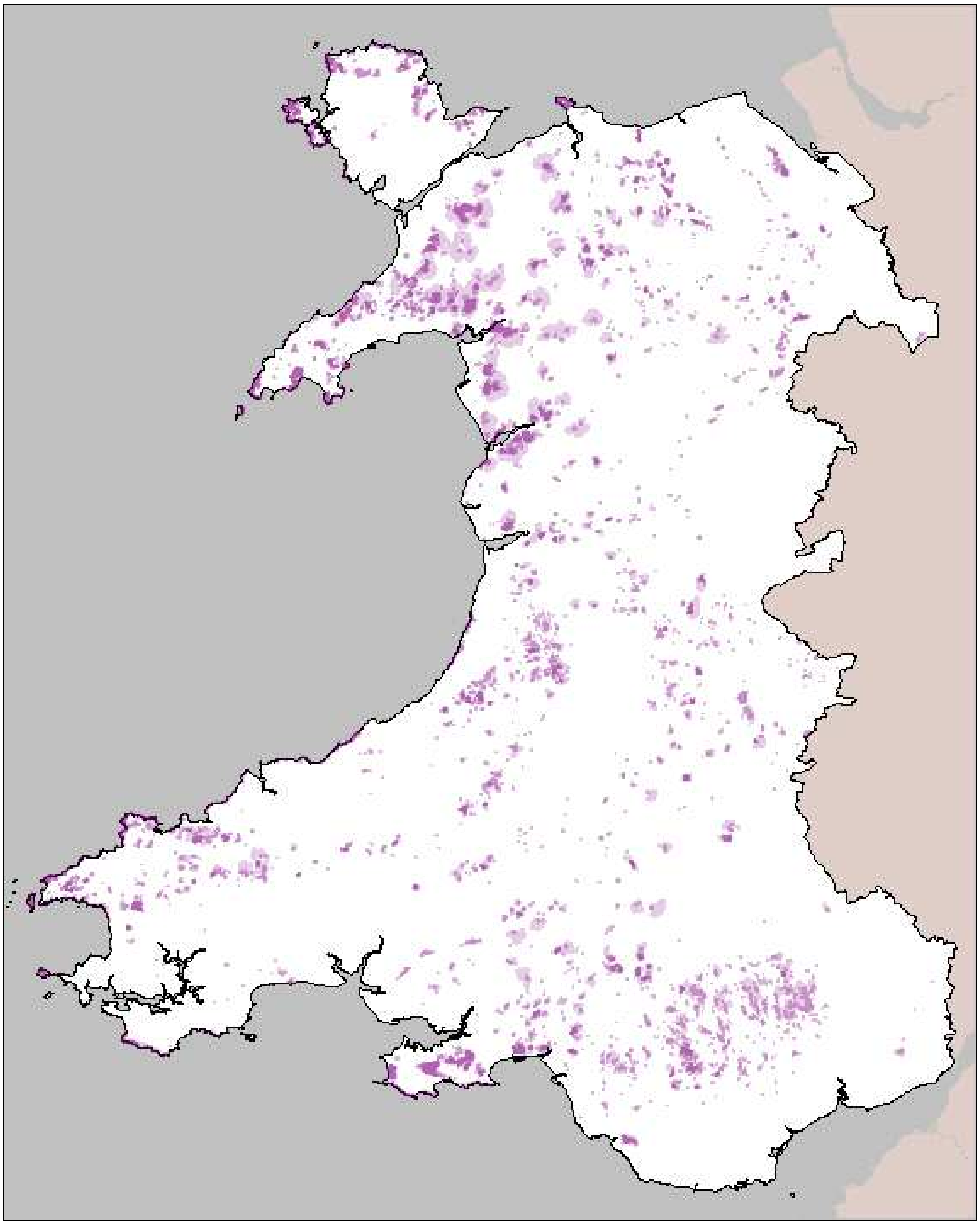


Figure 4. Lowland heathland habitat networks in Wales. Core, focal and local networks have been superimposed, and the depth of colour indicates the strength of ecological connectivity for this habitat. See text for details.

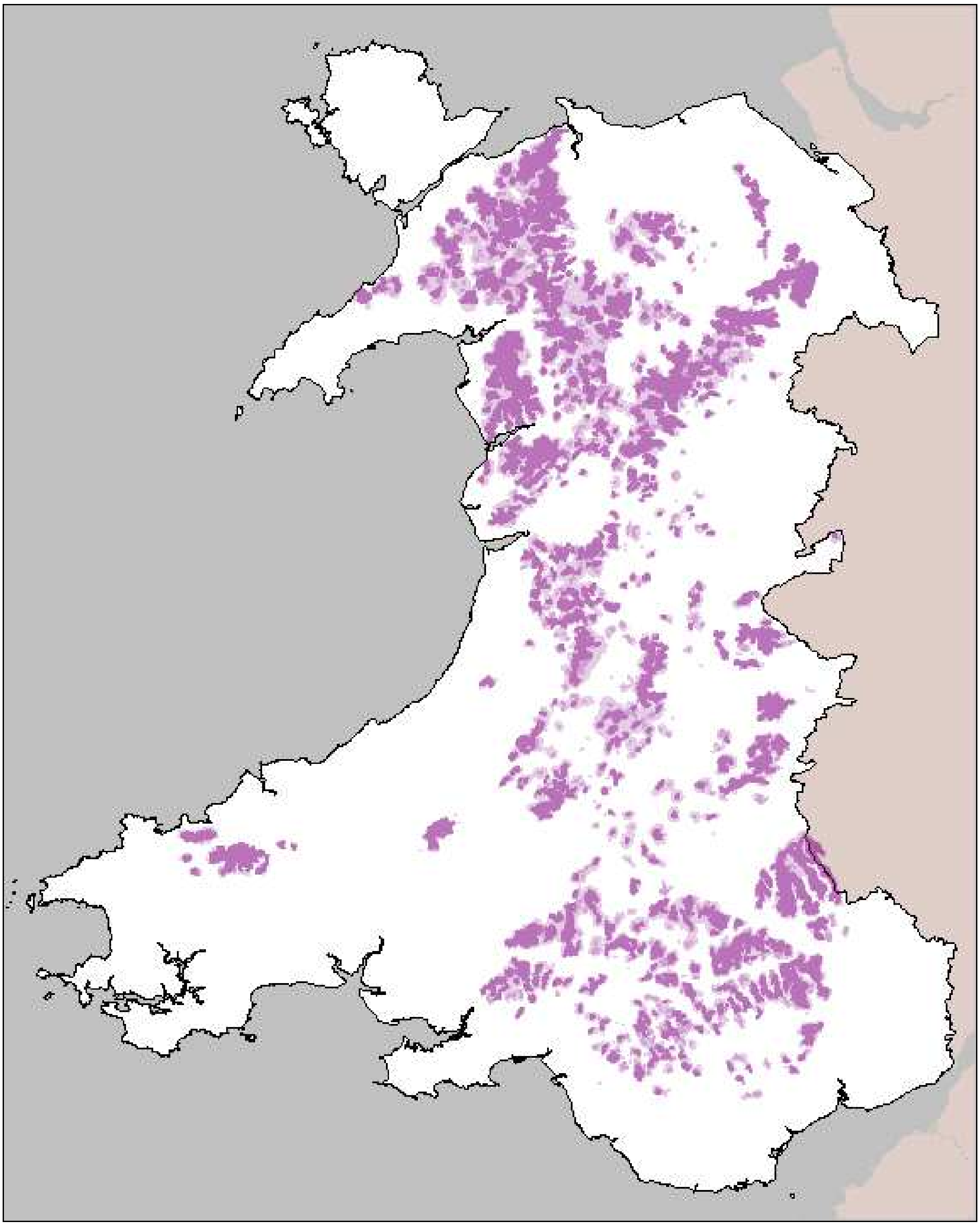


Figure 5. Upland heathland habitat networks in Wales. Core, focal and local networks have been superimposed, and the depth of colour indicates the strength of ecological connectivity for this habitat. See text for details.

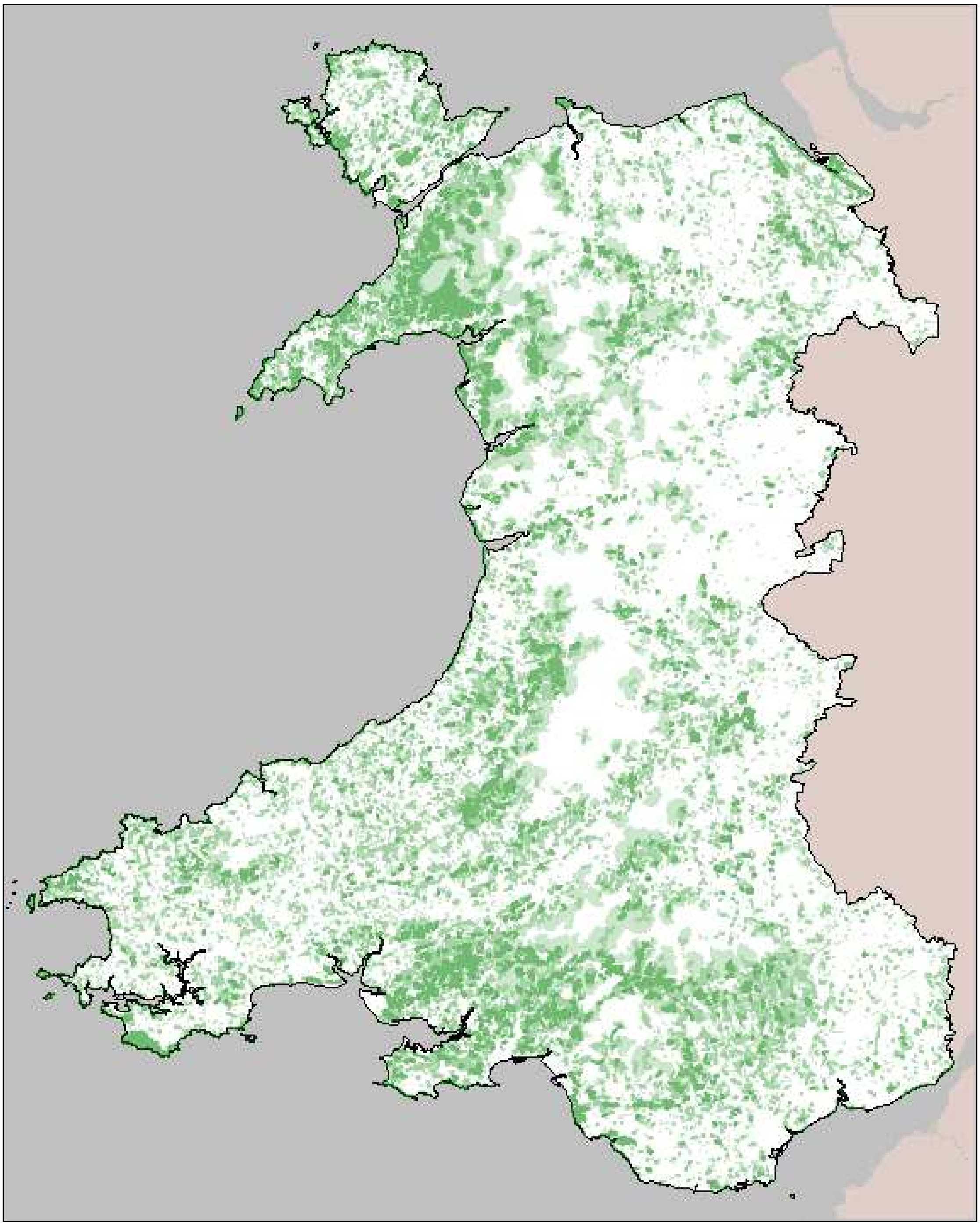


Figure 6. Lowland unimproved grassland habitat networks in Wales. Core, focal and local networks have been superimposed, and the depth of colour indicates the strength of ecological connectivity for this habitat. See text for details.

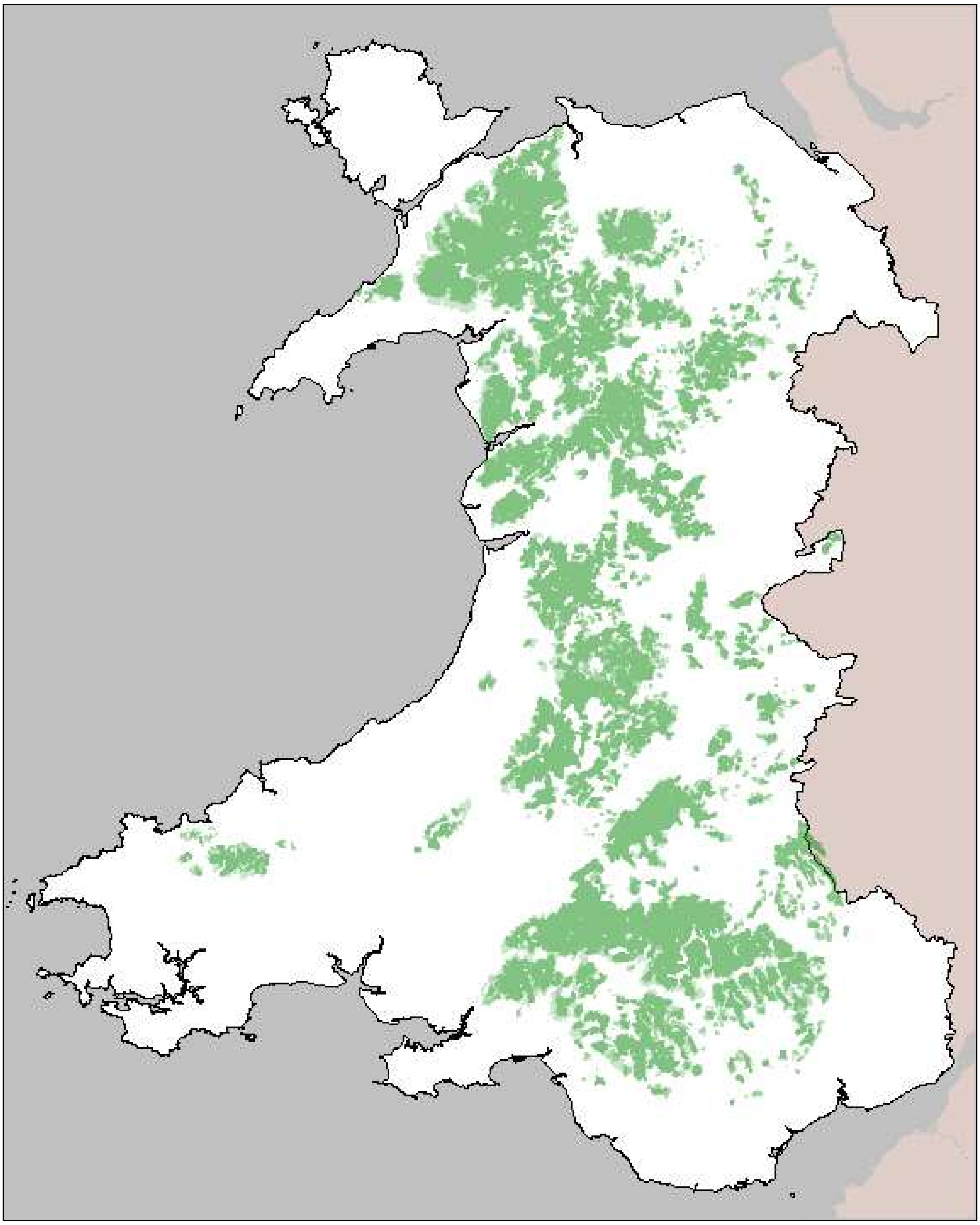


Figure 7. Upland unimproved grassland habitat networks in Wales. Core, focal and local networks have been superimposed, and the depth of colour indicates the strength of ecological connectivity for this habitat. See text for details.

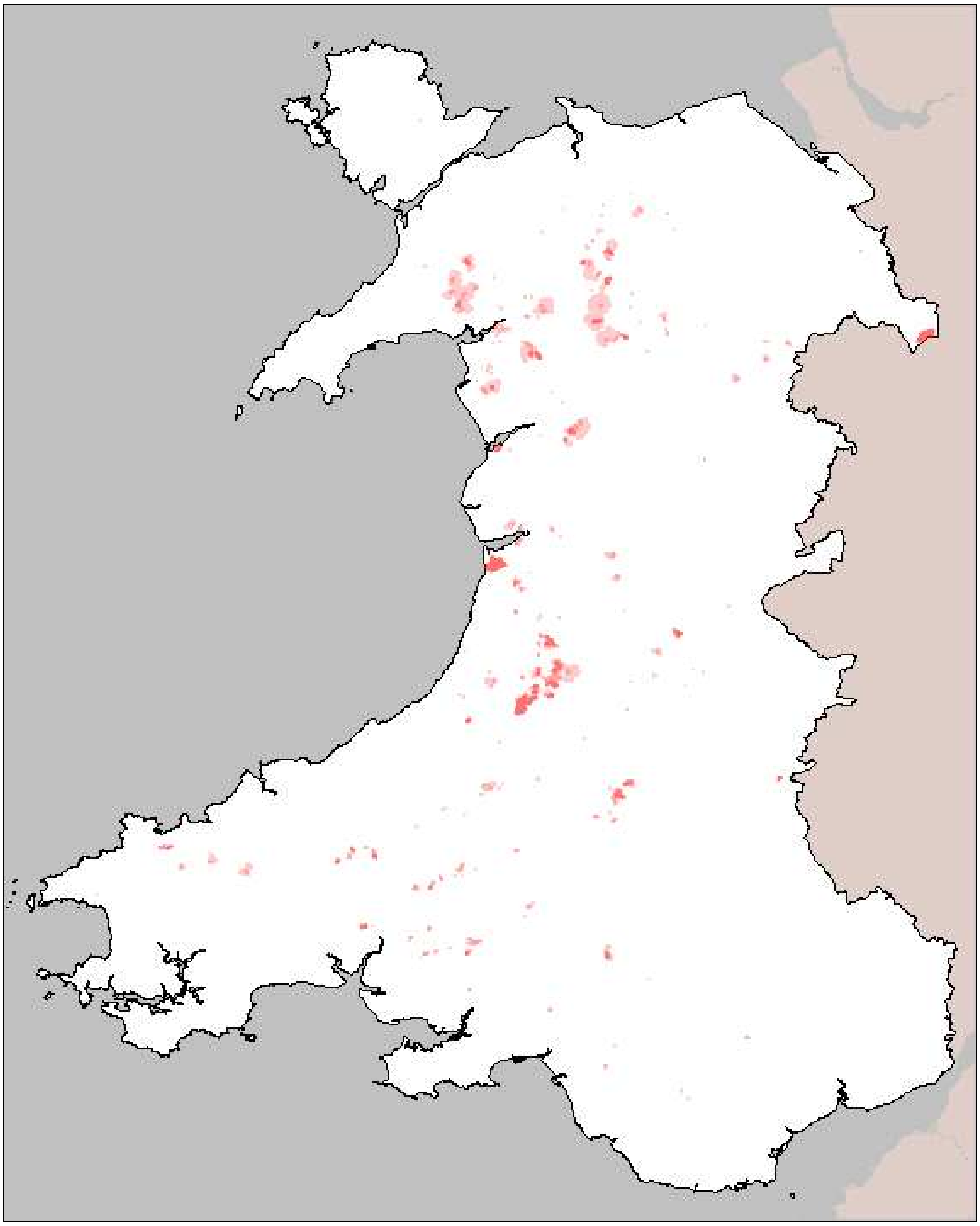


Figure 8. Lowland bog habitat networks in Wales. Core, focal and local networks have been superimposed, and the depth of colour indicates the strength of ecological connectivity for this habitat. See text for details.

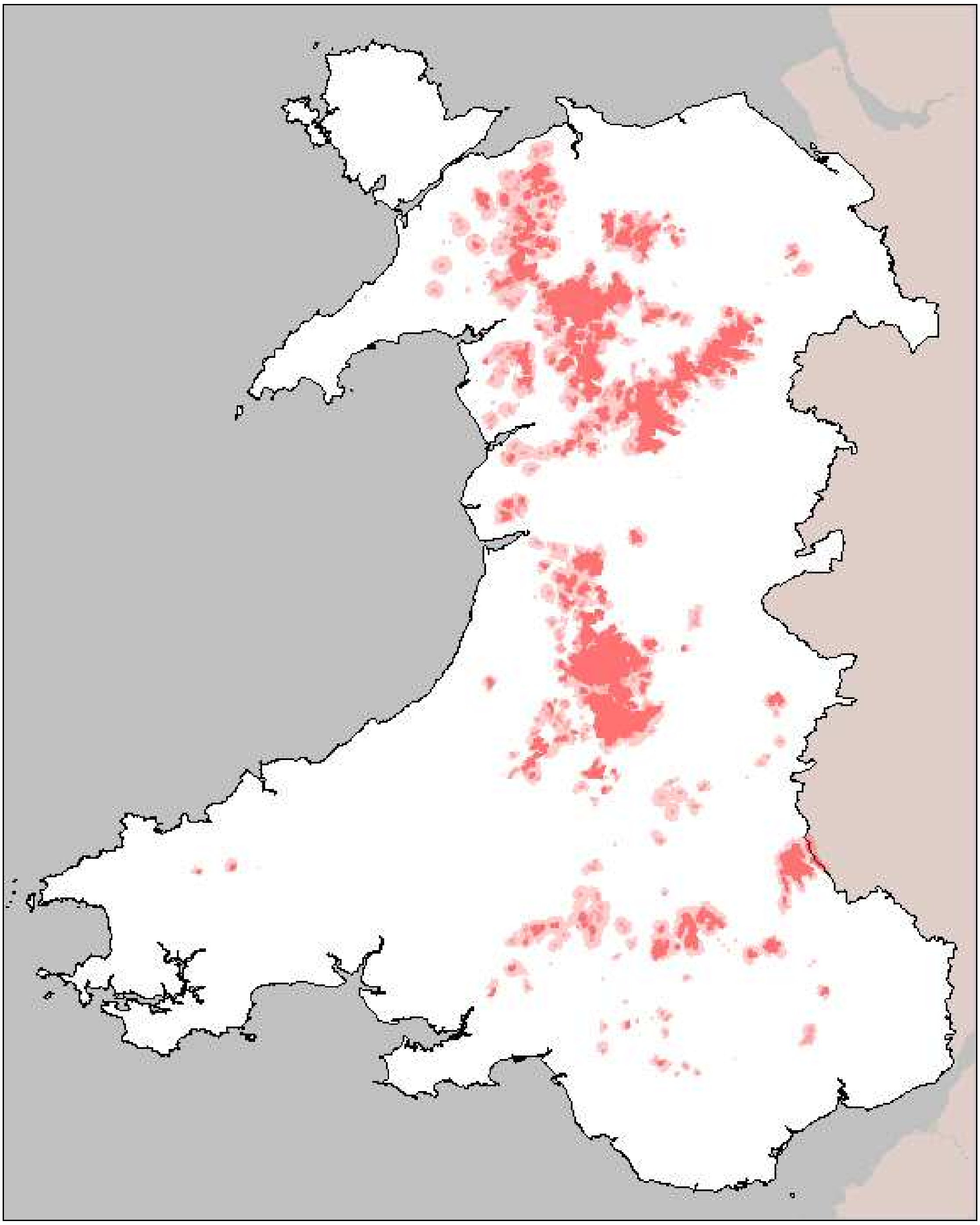


Figure 9. Upland bog habitat networks in Wales. Core, focal and local networks have been superimposed, and the depth of colour indicates the strength of ecological connectivity for this habitat. See text for details.

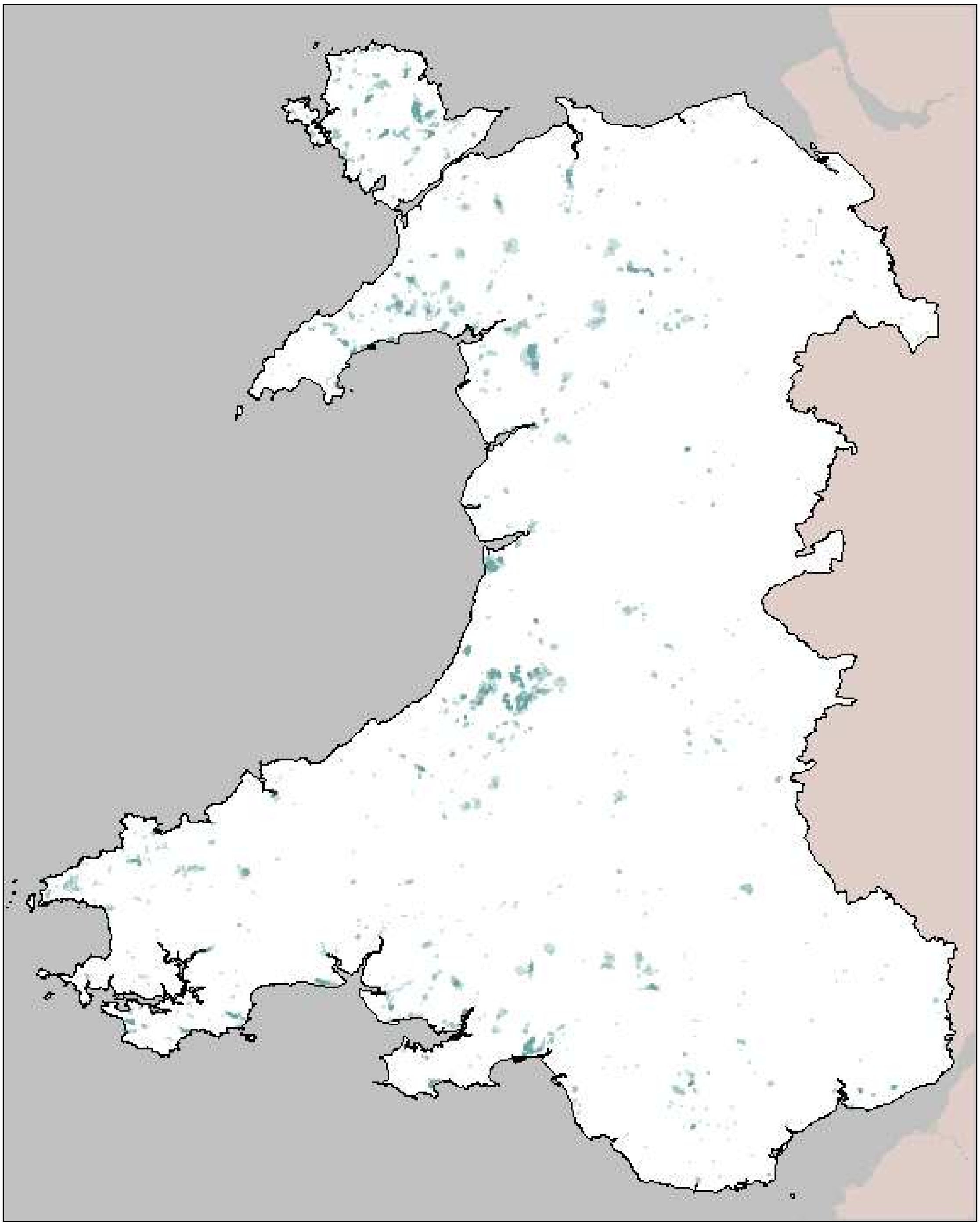


Figure 10. Lowland fen habitat networks in Wales. Core, focal and local networks have been superimposed, and the depth of colour indicates the strength of ecological connectivity for this habitat. See text for details.

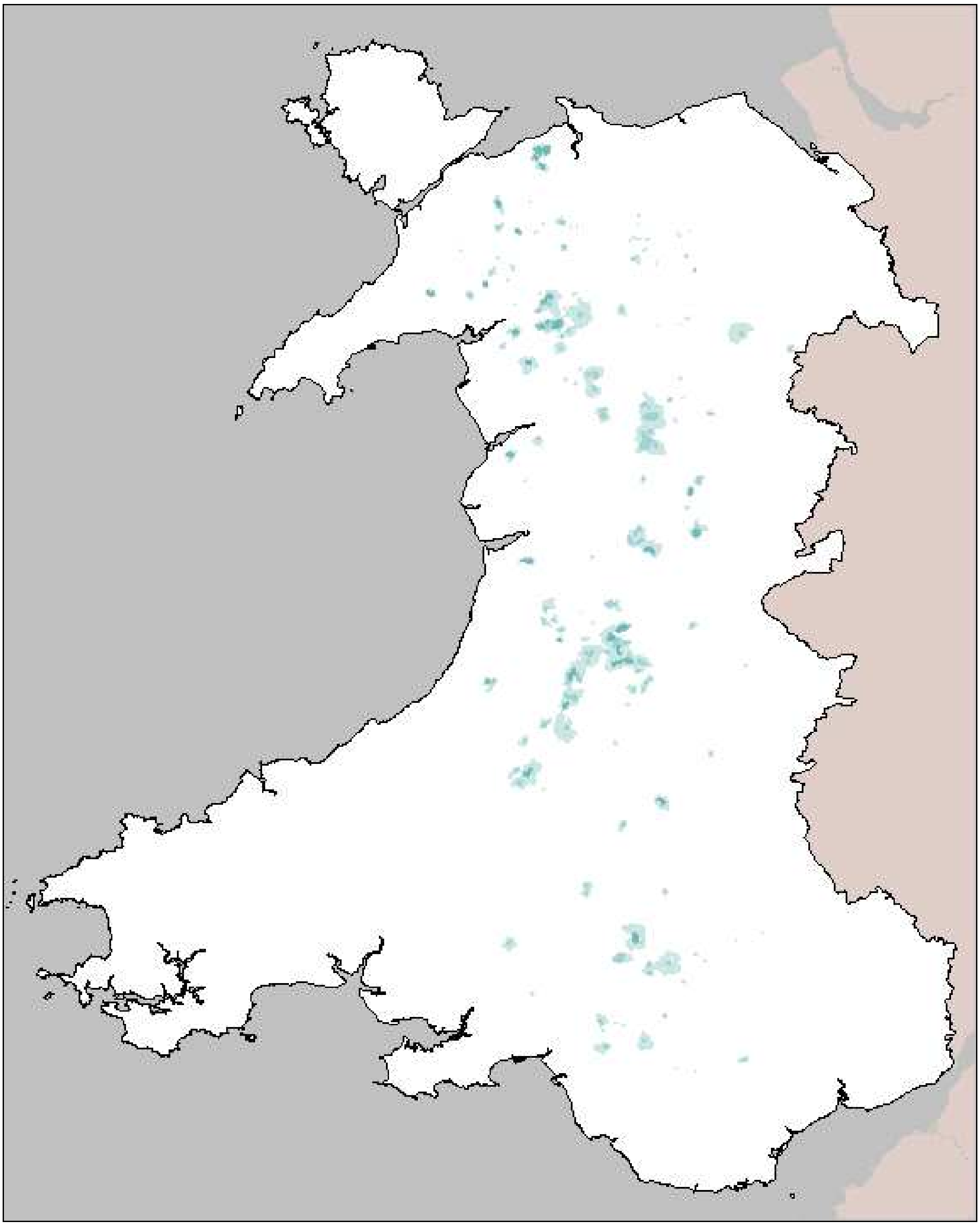


Figure 11. Upland fen habitat networks in Wales. Core, focal and local networks have been superimposed, and the depth of colour indicates the strength of ecological connectivity for this habitat. See text for details.

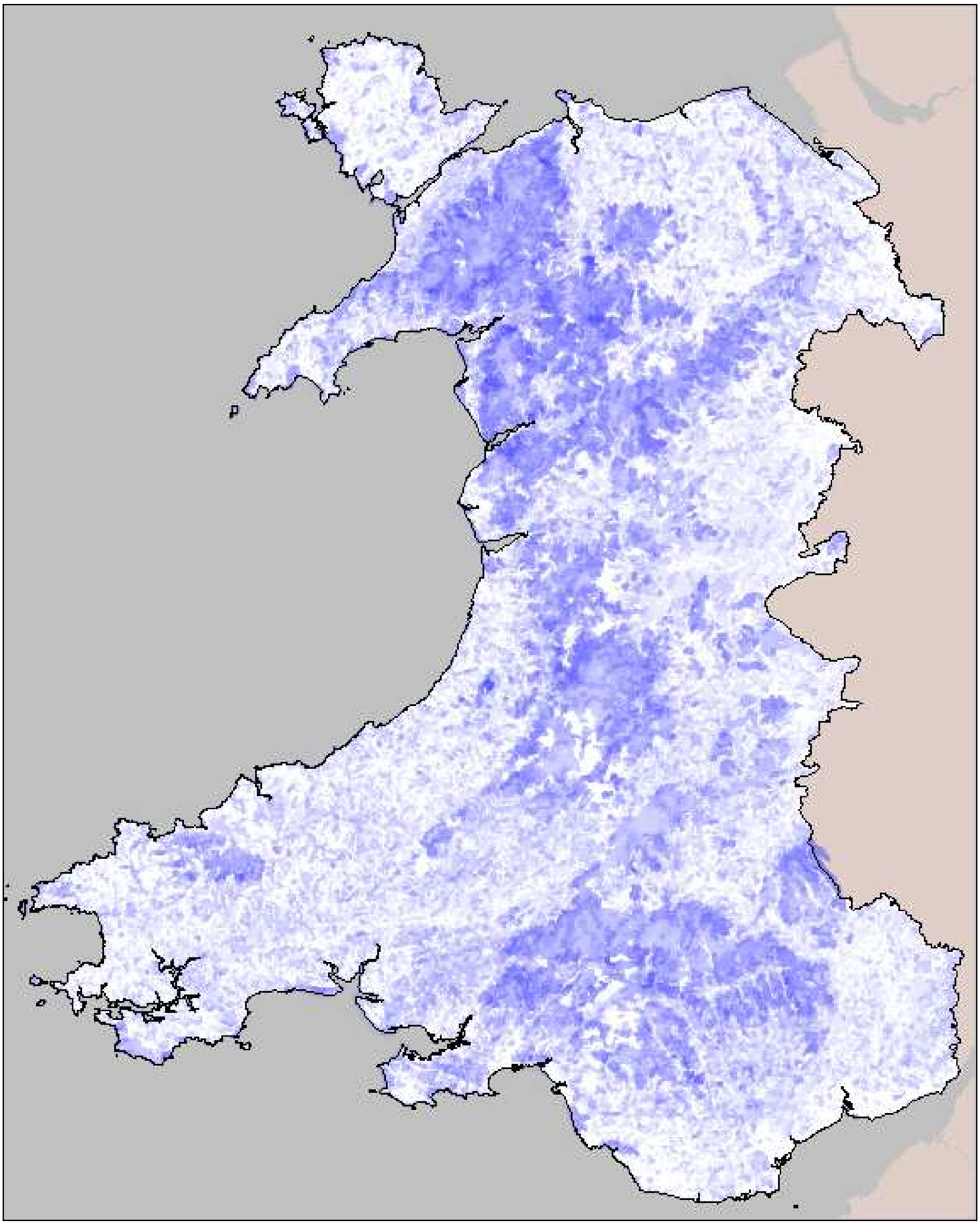


Figure 12. All habitat networks for woodland, heathland, unimproved grassland, bogs, fens and sand dune superimposed. The stronger the blue colour the more networks overlap, and hence the stronger the overall habitat connectivity. This provides a striking image of overall ecological connectivity for Wales, but is best considered a work in progress which will evolve as network mapping is refined and additional types of habitat networks are added (notably coastal habitats).

5.0 Uses of Networks

5.1 Overview of General Uses

The habitat network layers offer a general guide to how habitats are functionally related in the landscape, and therefore can be interpreted to help locate conservation action such as habitat restoration and expansion. In general terms, such action is likely to have most benefit if located within habitat networks, as it strengthens connectivity that is already likely to be present. However, in some cases ‘gaps’ in connectivity can be identified in pinch-points between networks, and new habitat patches, or stepping stones, within these could have considerable effect. The maps can also identify areas isolated from networks, within which new habitat may have relatively little benefit in terms of overall connectivity. Figure 13 gives examples of some of these general uses.

A common misconception is that network maps tell us exactly what habitats or ecosystems to establish at any given location. It is emphatically not our intention that the Network Tool is used in such a prescriptive manner. A typical example of this, is the assumption that woodland network maps define areas that should be completely planted with trees. This is not the case at all – they are predictions of the extent of *existing* functional connectivity that is present by virtue of current woodland cover and other semi-natural habitats that are functioning as an integral part of the network. The networks can be strengthened by additional planting, but this may only need to be small areas and judiciously located to avoid inference with the existing semi-natural habitats that make up the network.

The purpose of the network maps is to tell us something about how a large proportion of typical species of different habitats use the landscape and how we can improve permeability in the wider countryside to aid species movement and dispersal. By understanding connections at a landscape-scale we can prioritise how we protect, manage and enhance ecosystems to optimise biodiversity benefits in a manner appropriate to the location. Whilst network maps might help guide habitat creation at certain locations this is not their primary function and their use in this way would be to inform a local decision making process. Network maps will be used in a variety of other ways, for example, they may be used to prevent cumulative loss of biodiversity by identifying key networks which need to be protected and enhanced through Local Development Plans; they could be used to improve management within habitat networks which buffer and connect designated sites, as proposed in the Lawton Review (Lawton, 2010); or could help explore the effects of changing land management on ecosystem connectivity (see Section 6.0).

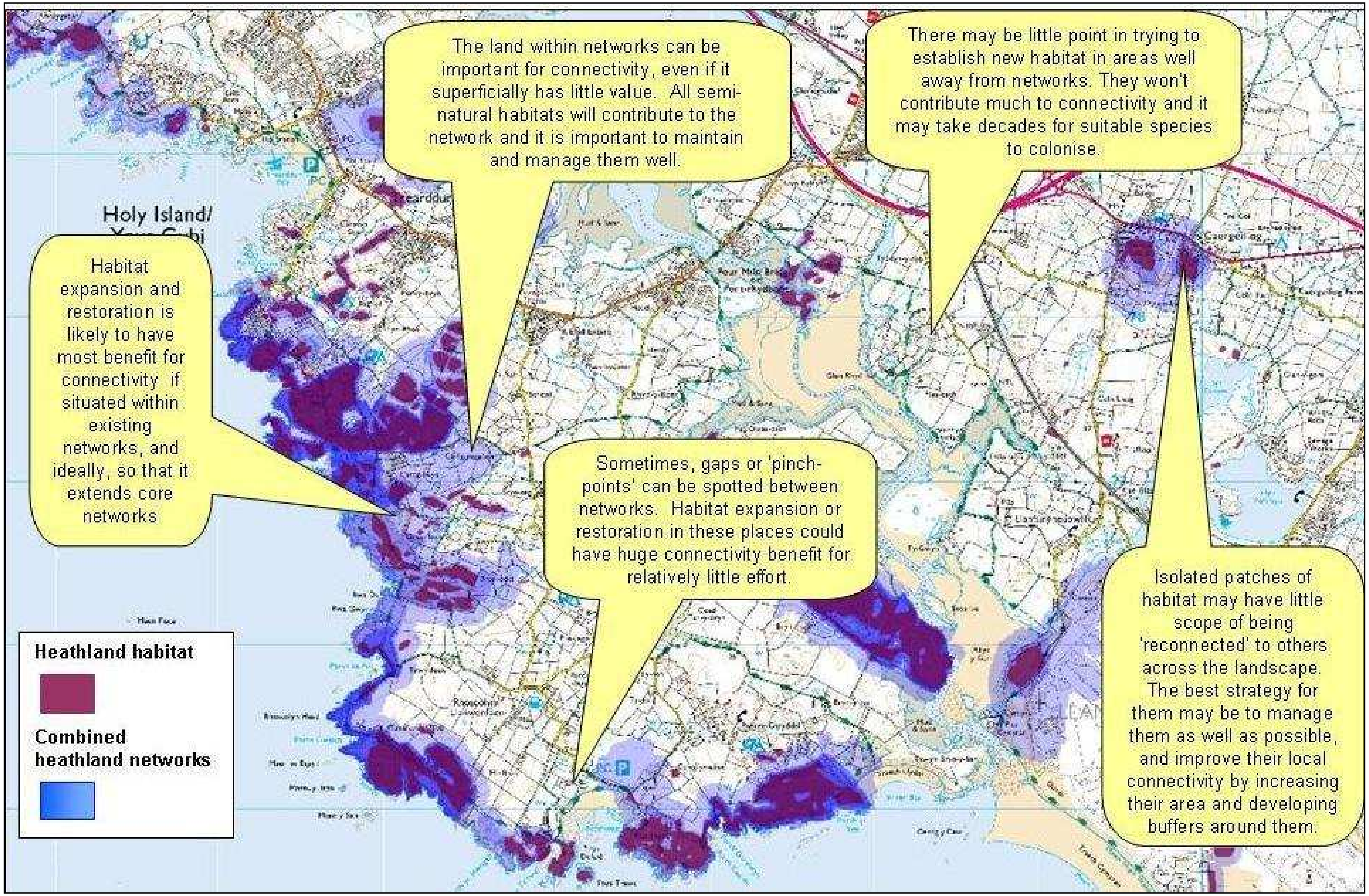


Figure 13. Examples of some of the ways in which habitat network maps can help guide the type and location of action for biodiversity

In summary it is our intention that the network maps feed into a variety of strategic plans, programmes and policies at the national, regional and local level. The list below is not exhaustive but gives an indication of the breadth of work within which network maps could be incorporated to promote the integration of ecological connectivity into decision-making processes.

- Local Development Plans (LDPs)
- Economic development policies
- Rural Development Plans (RDPs)
- National infrastructure planning e.g. the National Transport Plan
- Natural resources planning and management
- Ecosystem Services mapping
- Rights of Way Improvement Plans (ROWIPs) and other access plans
- Agri-environment targeting
- Green infra-structure plans
- National Park and AONB Management Plans
- Site notification programme for a robust and resilient protected site network
- Biodiversity offsetting and habitat banking
- Landscape-scale restoration projects e.g. LIFE and HLF

5.2 Application of Maps to Local Areas

A critical issue at the local level is the cumulative loss of biodiversity, the "death by a thousand cuts" challenge. The problem is that an individual site may not have sufficient interest on its own to merit prioritisation but it may form part of a key habitat/ecosystem network. The continual loss or degradation of such sites reduces the coherence of ecological networks and leads to habitat fragmentation with subsequent impacts on species populations.

Local Development Plans (LDPs) contain polices to protect a range of sites and features. These include designated sites such as SSSIs and in many cases non-designated sites referred to as second tier sites, Sites of Interest for Nature Conservation (SINCs) or Wildlife Sites. However the current approach does not usually protect areas crucial to maintaining connectivity between these sites. It is acknowledged that the lack of consideration of the wider environment including inter-site connectivity is a contributory factor in the failure of Wales to meet the 2010 biodiversity targets (National Assembly for Wales, 2011)

Strategic planning initiatives have, in recent years, begun to address biodiversity loss in the wider environment by incorporating thinking on connectivity and landscape permeability. The South East Wales Networked Environment Region (NER) Framework document (EDAW, 2009) for example states "*the NER will protect and enhance the environmental infrastructure of the city-region as the essential life support system for social and economic development, making the landscape* ***more permeable to wildlife*** *and more accessible for people, helping society and wildlife to adapt to climate change ………*". At the local level some unitary authorities are exploring the use of habitat network maps to identify strategic connectivity corridors.

These networks can form part of the authority's core biodiversity resource and as such can be given protection through the Local Development Plan. In addition network maps can be used in the development of biodiversity offsetting mechanisms by identifying appropriate locations for effective mitigation and habitat enhancement. An example is the innovative Biodiversity Management System developed in draft by Torfaen County Borough Council (2011), which embraced connectivity thinking and incorporated earlier versions of the CCW network maps. Although this system has not yet been adopted as Supplementary Planning Guidance it has provided a mechanism for ongoing discussions on cumulative biodiversity loss, offsetting and connectivity .

The Network Tool can also be employed to help plan and develop landscape-scale restoration projects, for example, as part of the local biodiversity action planning process. The network maps provide the strategic overview as a focus for discussion. Decisions on individual parcels of land need to be based on local knowledge to ensure consideration of issues such as land ownership, local community aspirations, archaeological sensitivities, physical site conditions e.g. geology, geomorphology, soils and topography and ongoing management concerns. For example the network maps were used on the Llŷn (Gwynedd) to guide discussions on the development of a landscape-scale habitat restoration project focused on the coastal belt.

5.3 Prioritisation Mapping

There is a demand for guidance on priority areas for conservation action. Resources seem to be ever diminishing, and need to be targeted to areas of highest value, those under greatest threat, and where there is greatest potential for benefit and success. This project aims to provide this guidance by identifying key concentrations of habitat and connectivity (for example that support Special Sites), and gaps where expansion and restoration could be targeted.

However, there is an inherent danger with identifying priorities, as non-priority areas could be perceived to have no value and may be damaged or lost. It is therefore very important to present priorities in a broader context, so that strategic priorities can be seen in relation to the local distribution of habitats and connectivity, which themselves may be important at a finer scale. To this end we have been promoting the idea of three nested levels of priority maps described below. Figure 14 gives an example of the approach for broadleaved woodland in southern Wales (from Latham & Sherry, 2011).

Level 1. Maps of the whole resource for each ecosystem, comprising habitat areas and the networks around them. As well as showing the area and distribution of each habitat, the network layers provide guidance on the connectivity and landscape relationships of all mapped habitat patches in Wales.

Level 2. Priority areas for conservation action: maintenance, restoration and expansion for each ecosystem. These have generally been identified by selecting out habitat networks (i.e. the spatial limits of 'ecosystems') that contain the most important areas (Special Sites or equivalent) for a given habitat, with expert interpretation to identify key gaps in connectivity. Level 2 maps are available in draft for several habitat groups, but require further development for release. The level is at a similar scale to that used for maps in the targeted element of Glastir, and has parallels to the 'restoration zones' described in the Lawton Report (Lawton, 2010). Work on Levels 1 and 2 has primarily been lead by habitat specialists in CCW's Terrestrial Ecosystems Group.

Level 3. This level includes actual locations where significant biodiversity loss is imminent and where resources need to be urgently targeted, as well as exemplar projects. Work on this Level is being lead by WBP Ecosystem Groups.

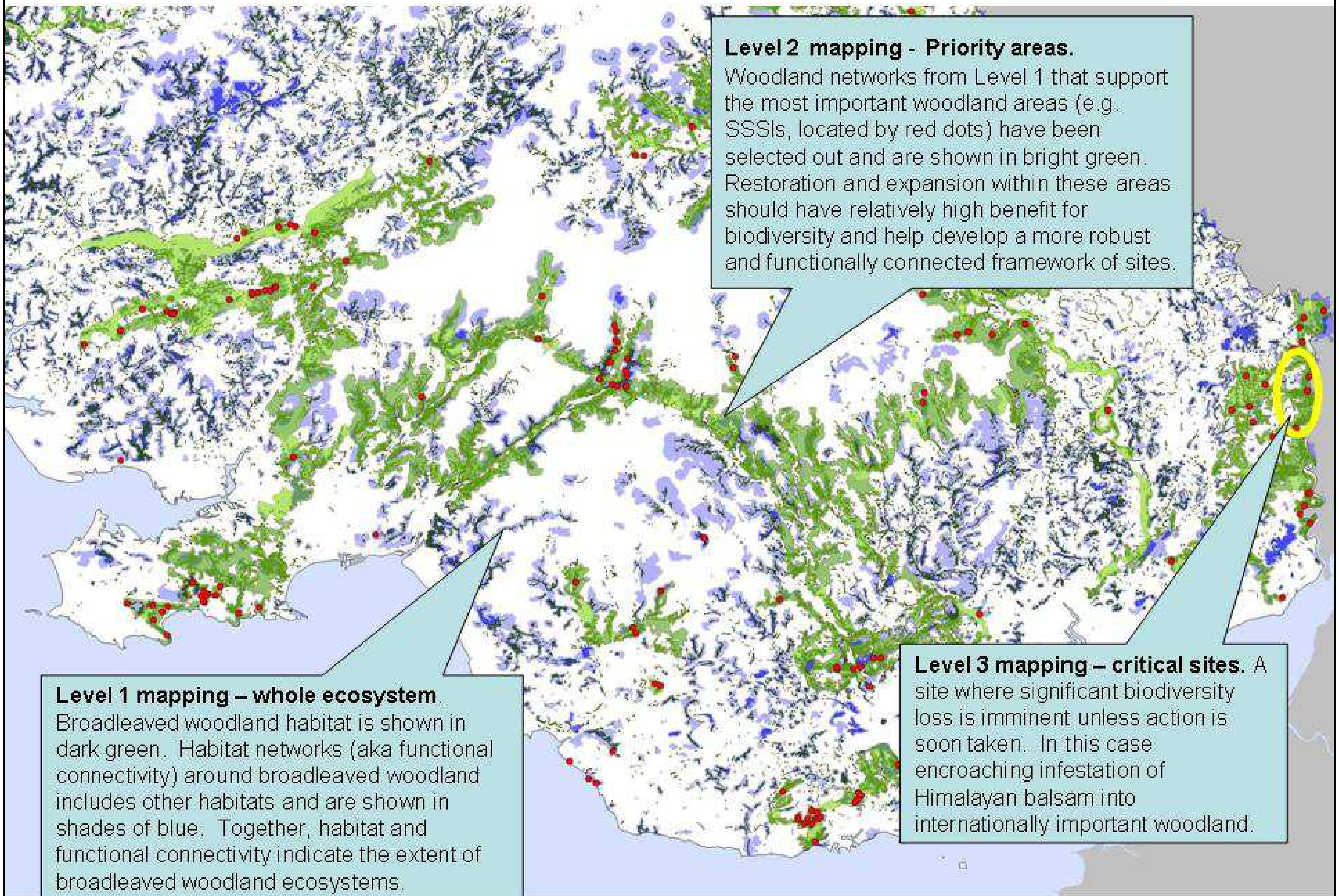


Figure 14. An example of Priority levels 1, 2 & 3 for broadleaved woodland in southern Wales.

6.0 Further Analysis and Relationships to Ecosystem Services

The mapping provides lots of opportunities for further analysis. A key feature of the connectivity mapping is that it takes into account the relative contribution of all habitats, so it is possible to take a much more integrated approach than simply looking at maps of habitats individually. For example, areas of connectivity for several habitats may overlap (see Figure 12), allowing areas of land with an important landscape function to be identified that otherwise would not have been appreciated as valuable.

NRW will be taking an Ecosystem Approach to its work (Spode *et al*., 2013) and the network layers could make a useful contribution (Thomas *et al*., 2013). When used in combination with other datasets they have the potential to identify key locations where biodiversity improvement may also benefit other ecosystem services.

An example is the relationship between areas identified as important for woodland expansion and those at risk from flooding. Carefully targeted increases in woodland cover could benefit biodiversity by consolidating key ecosystems, plugging gaps in connectivity and re-creating very rare floodplain woodland habitats, whilst also contributing to flood management in sensitive areas by slowing water flow on floodplains and increasing water infiltration on slopes; there may also be benefits in terms of carbon storage and recreation. Figure 15 gives an illustration of this for Bridgend, which combines EA flood maps with CCW's priority areas for woodland enhancement.

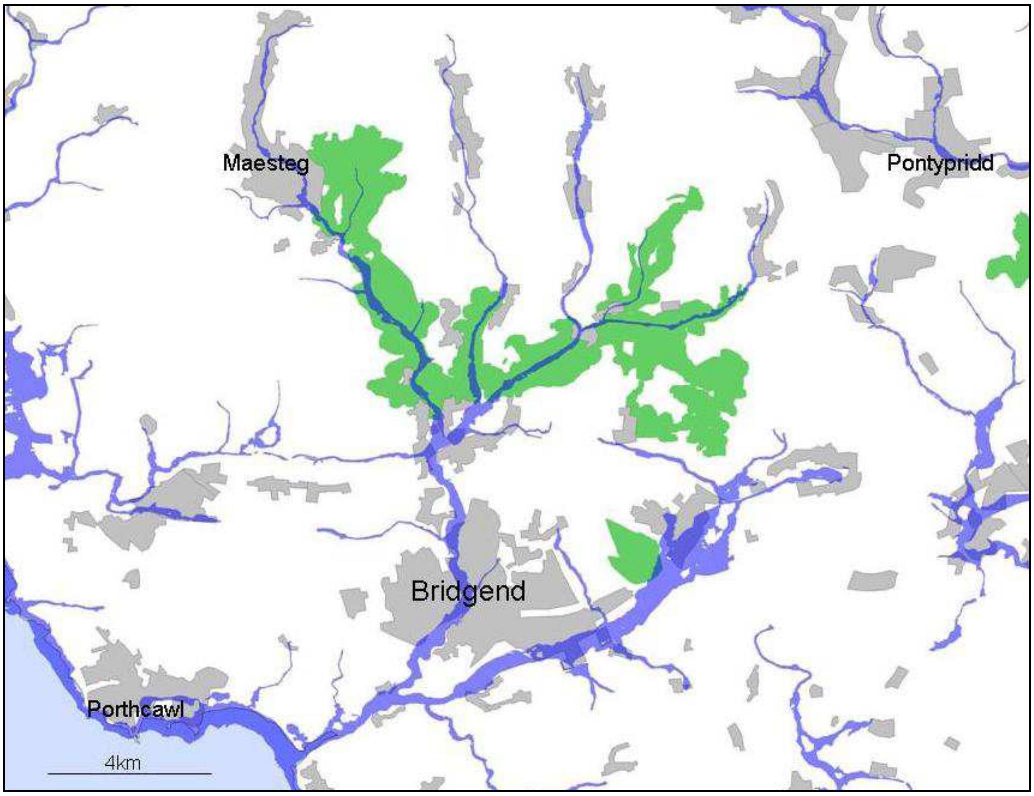


Figure 15. The relationship between priority woodland areas (green) and potential flooding (blue – EA's medium risk flood map) around Bridgend. An increase in woodland cover within the green priority areas would have significant biodiversity benefit whilst potentially also reducing flood risk downstream, notably along the Ogmore river which flows through Bridgend itself and has tributaries within woodland priority areas.

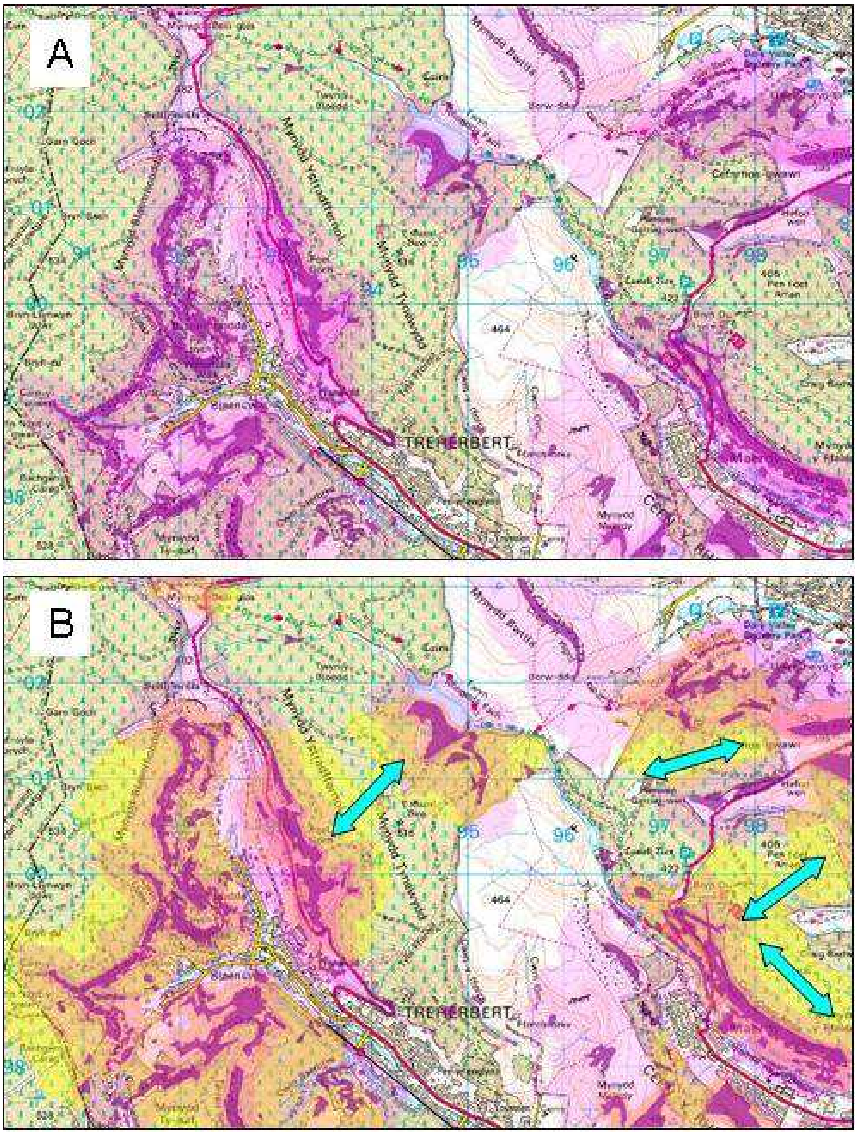


Figure 16. An example of interactions of forestry and heathland connectivity in the South Wales valleys. In A, heathland habitat is shown in purple and the habitat networks around it in pink. B shows a result of remodelling heathland networks but with increased permeability of conifer plantation: the additional core network extent that arises from this is shown in yellow, with key potential connections indicated by blue arrows. See text for further information.

A second example of links to ecosystem services is shown above in Figure 16 , where the possible effects of conifer plantation re-structuring on heathland connectivity have been explored by re-running the model with increased permeability for conifer plantation. Areas with dense conifer forestry can be picked out that form potential connections between heathland blocks, although in their current condition they are relatively impermeable to heathland species. This does not necessarily imply that forestry in these areas should be replaced by heathland, rather that the forestry could be managed in a manner which increases permeability to heathland species. This could be by widening paths and rides, felling coupes rotationally to create a mosaic of sequential heathland and forestry regeneration which is beneficial to species such as nightjar, or by thinning to create a more open wood pasture structure. If considered alongside local access plans, forestry management to improve biodiversity could also enhance opportunities for public access and enjoyment in this relatively densely populated area, thus increasing the benefits for both wildlife and people whilst maintaining timber production. This example highlights the added value of using network maps alongside other strategic plans and initiatives to provide multiple benefits.

NRW has great potential to advance projects like the two examples above as the organisation will encompass expertise in all aspects of ecology and resource management.

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8.0 List of Abbreviations

AONB	Area of Outstanding Natural Beauty
AWI	Ancient Woodland Inventory
CCW	Countryside Council for Wales
EA	Environment Agency
FCW	Forestry commission Wales
FR	Forest Research
HLF	Heritage Lottery Fund
LBAP	Local Biodiversity Action Plan
LDP	Local Development Plan
LISS	Low Impact Silvicultural System
NER	Network Environment Region
NRW	Natural Resources Wales
PAWS	Plantations on Ancient Woodland Sites
RDP	Rural Development Plan
ROWIP	Rights of Way Improvement Plan
SINC	Sites of Importance for Nature Conservation
WBP	Wales Biodiversity Partnership
WG	Welsh Government