Natural England Research Report NERR081

Nature Networks Evidence Handbook

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Published 6 March 2020

ISBN 978-1-78354-585-8

Project details

This report should be cited as: Crick, H. Q. P., Crosher, I. E., Mainstone, C. P., Taylor S. D., Wharton, A., Langford, P., Larwood, J., Lusardi, J., Appleton, D., Brotherton, P. N. M., Duffield, S. J. & Macgregor N. A. (2020) *Nature Networks Evidence Handbook*. Natural England Research Report NERR081. Natural England, York.

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Acknowledgements

This handbook has benefitted from many inputs during the course of its creation, and we would like to thank our colleagues in Natural England: Ian Alexander, Isabel Alonso, Chris Bolton, Andy Brown, Eleanor Brown, Corrie Bruemmer, Gary Charlton, Susan Clark, Christina Cork, Jonathan Cox, Alistair Crowle, Iain Diack, Helen Doran, Allan Drewitt, Jeff Edwards, Dawn Enright, Wanda Fojt, Emma Goldberg, Mike Grace, Paul Green, Phil Grice, James Grischeff, Clare Howe, Richard Jefferson, Joanne Keegan, Ben le Bas, Brian McDonald, Edel McGurk, Michael Morecroft, Andrew Nisbet, Stuart Pasley, Colin Prosser, Frances Randerson, Sue Rees, Tony Robinson, Matthew Shepherd, Tim Sunderland, Orlando Venn, Wilbert van Vliet, Ruth Waters, Jon Webb, Nick White, Richard Wilson, Jane Wright, Richard Wright, as well as members of the Natural England Science Advisory Committee (Andy Clements, Joe Horwood, Maggie Roe, Janet Hooke, Keith Kirby, Richard Bradbury, Lynn Crowe, Mariecia Fraser & Piran White). Comments and help from colleagues outside Natural England were also very helpful: Colin Beale, Paul Bellamy, Jenny Hodgson, Steve Palmer, Bob Smith and Kevin Watts.

Executive Summary

1. The overarching ambition of the Defra 25 Year Environmental Plan is to 'leave our environment in a better state than we found it and to pass on to the next generation a natural environment protected and enhanced for the future' (Defra 2018a). The plan highlights six key areas for action, one being to establish a Nature Recovery Network. This will protect and restore wildlife, as well as providing greater public enjoyment of the countryside; increased carbon capture; and improvements in water quality and flood management.

2. This handbook aims to help the designers of nature networks by identifying the principles of network design and describing the evidence that underpins the desirable features of nature networks. It builds on the *Making Space for Nature* report of Lawton *et al.* 2010), outlining some of the practical aspects of implementing a nature network plan, as well as describing the tools that are available to help in decision making.

3. To make a *nature* network, in contrast to an ecological network, we need to involve people from the earliest stages in planning and design, to create an overarching vision for the network, taking into account their needs and the services that a landscape provides to society.

4. When developing a more detailed plan for a nature network, it is important to consider the constraints and opportunities provided by the landscape, geology and ecosystems within the landscape, and the need to build resilience to climate change.

5. We provide a suite of ecological rules of thumb to aid practitioners, including a hierarchy of priority actions: (a) improve core wildlife sites; (b) increase the size of core sites; (c) increase the number of core sites; (d) improve the 'permeability' of the surrounding landscape for the movement of wildlife; and (e) create corridors of connecting habitat. In addition there is a need to develop a number of Large Nature Areas (c. 5-12,000 ha) within a country that will provide centres from which wildlife will brim over into the countryside.

6. When implementing the plans for a nature network there are various key practical aspects that need to be considered: working within the planning system, working with landowners and farmers and working with the natural processes that operate within a landscape.

7. We describe a number of mapping datasets and decision support tools that are available to help those planning a nature network, but their use needs to be carefully considered with respect to data quality, spatial scale, level of model complexity and uncertainty.

8. The main results of this evidence review are provided in a shorter *Summary for Practitioners* (Crick *et al.* 2020).

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1 Preparation – identify and build a delivery partnership, develop a shared vision, agree objectives

Summary

- Despite some conservation successes, we have lost much nature and are still losing it: some species have become extinct in England and many hundreds more are threatened with extinction. The rate of loss is damaging for the provision of ecosystem services, including the sheer enjoyment to be obtained from a countryside full with abundant wildlife.

- A solution is to develop a coherent ecological network that makes existing sites and patches of habitat better and bigger, increases the number of valuable habitat patches, improves connectivity, and restores natural processes so the ecosystems are more sustainable.

- To make an ecological network into a nature network, we need to involve people from the earliest stages in planning and design, taking into account their needs and the services that a landscape provides to society.

- We have identified 10 Principles for Nature Network Design to help in this planning process.

- In engaging people, it is helpful to develop a 'stakeholder map' to identify key participants for developing a vision for a network. Participatory approaches increase in effectiveness from informing and consulting, through to collaboration and empowerment. However more inclusive forms of engagement require greater resources.

1.1 Introducing the problem and defining the issues

The overarching ambition of Defra's 25 Year Environmental Plan is to 'leave our environment in a better state than we found it and to pass on to the next generation a natural environment protected and enhanced for the future' (Defra 2018a). The plan highlights six key objectives, one being that 'we will achieve a growing and resilient network of land, water and sea that is richer in plants and wildlife'. The 'Nature Recovery Network' envisaged by the plan will build on the Making Space for Nature report (Lawton et al. 2010) which recommended the development of a 'coherent ecological network in England to help counter habitat loss and fragmentation and declining habitat quality as a result of a range of pressures including land use change, the intensification of agricultural management, disturbance, pollution, nutrient enrichment and climate change.

An **ecological network** can be understood as a number of core, well connected, high quality areas of well-functioning ecosystems, together with those parts of the intervening landscape that are 'wildlife-friendly' and which, collectively, allow wildlife to thrive. As well as having a primary role of supporting abundant wildlife, a **nature network** should also enhance natural beauty, heritage and conserve geodiversity and opportunities should be taken to deliver benefits for people, such as flood alleviation, recreational opportunities and provide nature-based solutions to climate change adaptation and mitigation. These joint aims, for nature and people, are at the heart of Nature Networks and they are inter-dependent: networks for wildlife that also deliver benefits to people and are valued by people. Thus they are likely to receive greater investment and protection by society and consequently provide more for nature and be more sustainable in the long term.

This handbook aims to help the designers of nature networks by identifying the principles to underpin network design, as well as suggesting ways of working with others. The handbook also highlights a suite of ecological 'rules of thumb' that are backed up by a detailed review of evidence and provides an overview of the range of mapping tools that practitioners might use. It is worth noting at the outset that although nature networks should reflect national priorities, local circumstances will require local solutions, based on local knowledge, so the suggestions made below will need to be adjusted appropriately. This handbook will only be a starting point, as many of the topics covered could well be books in their own right and we don't presume to have all the answers. However we will provide pointers to further literature and sources of information that may be helpful.

We start with an overview chapter that outlines the problem of declining biodiversity, how Sir John Lawton and a group of experts reviewed the protected area network in England and concluded that this needed to be strengthened into a 'coherent ecological network', and how an ecological network based on ecological principles needs to have people at its heart to become a nature network, as envisaged in Government's 25 Year Environmental Plan. While this handbook concentrates on the development of a terrestrial network, many of the principles will be applicable to the marine environment.

1.1.1 Nature is being lost

Before getting into the detail of the components of nature networks, it is worth briefly providing some background to place this work in context. Conservation in England has largely focussed on protected sites, priority habitats and rare species, and has used agri-environment (incentive) schemes to help the conservation of widespread yet declining species in a countryside dominated by farmland and woodland and increase the environmental quality of the wider landscape. There have been notable successes with these approaches. We have, for example, re-instated lost populations of species (e.g. dormouse *Muscardinus avellanarius* (Chanin 2014) and wart-biter cricket *Decticus verrucivorus* (Curson 2016)), and restored species populations such that they can be removed from the UK Biodiversity Action Plan priority list (e.g. prickly sedge *Carex muricata ssp. muricata* and Adonis blue butterfly *Lysandra bellargus*) (BRIG 2007).

However, as successive *State of Nature* reports show (Burns *et al*. 2013; Hayhow *et al*. 2016, 2019), the general picture for biodiversity in the UK remains one of decline. Nearly 500 species have been lost entirely from England, mostly in the last 200 years (Natural England 2010) and these recorded losses may under-estimate the true extinction rate, particularly for less well known groups (Hambler *et al*. 2011). Furthermore, losses have not been confined to rare or range-restricted species; many once abundant and ubiquitous species have declined substantially to the extent that some have become range-restricted, rare or regionally extinct as a consequence.

There continue to be many localised extinction events; for example, on average, one species of flowering plant is lost from each English county every two years, with the greatest rates of loss in the south and east (Walker 2003). There have been rapid losses (of more than 50% in the last 25 years) of once common species such as hedgehogs *Erinaceus europaeus*, house sparrows *Passer domesticus* and common toads *Bufo bufo*, and extinction of many species from parts of their former ranges (Burns *et al.* 2013). The index of farmland bird populations in England is at about 43% of its level in 1970, with tree sparrows down by 96% and turtle doves down by 98% (Defra 2018b, Massimino *et al.* 2017). Over the UK as a whole, the populations of habitat-specialist butterflies have fallen by 74% and of those in the wider countryside by 57% since the 1976 (Defra 2017). Overall, across our best-known groups, about a quarter of all species are at historically low levels or significantly threatened (Natural England 2010). Amongst these, specialist species (those with relatively specific habitat requirements) have tended to decline faster than generalists (which occupy broader niches), leading to a decline in the variety of species in England's natural environment (Clavel *et al*. 2011, Ross *et al*. 2012, Carvalheiro *et. al*. 2013).

There have also been substantial losses of many habitats: semi-natural habitats now being largely confined to small and isolated fragments, particularly in the lowlands (Lawton *et al*. 2010). The largest twentieth century decline was that of species-rich grasslands, of which 97% were lost between the 1930s and 1980s (Fuller 1987). There have also been large losses of ancient woodland (Hopkins & Kirby 2007). Not only have habitats been lost but their quality has been degraded, often through the restriction or changing of the natural ecological processes that should occur within them, for example through channelizing streams, draining wetlands, changing grazing or disturbance regimes (Mainstone *et al*. 2018).

The main causes of current habitat loss and degradation are: direct losses to agricultural intensification, inappropriate management, development and pollution (JNCC 2010). For example, nutrient enrichment and reduced management have led to losses of short-stature, stress-tolerant plant species and increases in nutrient-loving tall herbs (Preston *et al.* 2002; Carey *et al*. 2008, Countryside Survey 2009). Nitrogen deposition is detrimental to many uplands habitats (Countryside Survey 2009) and 50% of river stretches are at risk of failing Water Framework Directive quality objectives due to diffuse phosphate pollution (Mainstone *et al*. 2008).

The impact of climate change on the natural environment is already very apparent (Morecroft & Speakman 2013), and is an increasing threat to many species (Pearce-Higgins *et al.* 2017) and hence to habitats and ecosystems, and to the services they provide. Although the range of some species are projected to expand under climate change, many are not able to keep pace with expected range changes e.g. southern amphibians and reptiles do not appear to be spreading north, presumably due to a lack of available habitat, poor dispersal abilities or barriers to movement (Hickling *et al*. 2006). Habitats are changing as component species start to shift their range.

Fragmentation of habitat patches is also a key driver of species loss and declining habitat quality (Hooftman & Bullock 2012). As habitats become more fragmented and isolated, the remaining patches are often more difficult to manage effectively, are subject to edge effects, and become less suitable for species with larger home ranges. The species within them are liable to suffer loss of genetic vigour and be prone to invasion by competitive and non-native species (Fahrig 2003, Lawton *et al*. 2010, Knight *et al.* 2014). As a result of fragmentation, we are left in many places with small nature 'islands' scattered in a rather unfavourable landscape. The principles of island biogeography dictate that bigger islands have higher diversity and that smaller distances between islands increase the survival of species (Macarthur & Wilson 1967). This also applies to nature conservation sites: smaller sites risk losing populations, while recolonisation from other sites and habitat patches is less frequent with larger separation distances.

Many of these nature 'islands' are designated as statutorily protected areas (PAs) or are protected through the efforts of non-governmental conservation organisations. Well-designed and effectively-managed systems of protected areas are a vital tool for reducing biodiversity loss while delivering environmental goods and services that underpin sustainable development (Ervin *et al.* 2010). However, PAs in the UK were often originally chosen to be the best examples of particular habitats or for specific concentrations of species, drawing on the ground-breaking *Nature Conservation Review* (Ratcliffe 1977). As such, they have three features that limit their effectiveness as the basis for a nature network (Shwartz *et al*. 2017): they are often small and isolated, and so cannot maintain broad-scale ecological processes or sustain viable populations of wide-ranging species (Lawton *et a*l. 2010); they are often placed in remote areas with little economic potential (Oldfield *et al*. 2004), leaving many ecosystems and species poorly represented (Jackson and Gaston, 2008); and they tend to fix conservation efforts in space, based on conditions at a certain time, while ecosystems and their threats are dynamic (e.g. Araújo *et al*. 2011). A new approach to species and habitat conservation is therefore required, that views protected areas as part of a coherent ecological network at a landscape scale (Lawton *et al.* 2010).

1.1.2 Losses of ecosystem services

The loss of biodiversity and areas of well-functioning ecosystems is also important for society, because we are losing the many benefits that flow from them. The UK National Ecosystem Assessment (UKNEA 2011, 2014) showed how much our society benefits from the wide range of services that our ecosystems provide. The UKNEA also identified the drivers that are adversely affecting these ecosystems and services, including loss of habitat extent and condition, pollution and nutrient enrichment, climate change, invasive non-native species and over-exploitation of resources such as fisheries, timber, water abstraction and livestock stocking rates. Whilst we are dependent on ecosystems for vital well-being benefits (e.g. Natural England 2009), the declines in our natural environment have meant that we have suffered from the damaging impacts of human activities and natural events. For example, the loss of well-functioning upland blanket-bogs can result in discolouration of drinking water, requiring costly treatment before being put into the supply system. At the same time, enhancing the natural environment can enhance the well-being benefits we get from it, and provide solutions to environmental pressures. Air quality could be improved in towns by the appropriate planting of natural vegetation to capture particulate pollution from vehicles. Coastal salt-marsh can, in some areas, provide a very cost-effective sea-defence against increased storm surges that occur with sea-level rise that would otherwise have the potential to cause major disruption to communities and farming. Tree planting in upland areas, where the rain falls heaviest, can help to reduce flooding downstream, in addition to locking up carbon within the trees and reducing losses of carbon from soils. Green spaces provide proven benefits for human health and well-being, with psychological benefits being very important for society.

Thus the degradation of the natural environment has meant that nature is working less well for society than it could do. The development of a nature network will help restore many of these ecosystem functions and improve the services upon which society depends, as well as benefitting nature. As for wildlife, the location of habitats in a nature network affects the benefits that we receive. For example, although the planting of trees will provide benefits for mitigating climate change irrespective of their location, their placement needs to be carefully planned to help improve water quality or downstream flood risk. Similarly, the position of habitats or trees in cities affects whether they mitigate noise or air pollution, provide shade for local cooling or accessible green spaces near to where people live. Many of the services we get from nature will become even more important in the future as nature-based solutions to climate change. A well-designed nature network, based on well-functioning ecosystems, could contribute greatly to helping society adapt to the predictable and unpredictable consequences of climate change in the future.

1.1.3 How ecological networks can help

The *Making Space for Nature* report (Lawton *et al.* 2010) encouraged the development of a 'coherent ecological network' in England to help counter these pressures and to allow nature to re-establish and flourish. An ecological network comprises a suite of high quality wildlife sites, and associated surrounding habitats, which collectively contain the diversity and area of habitat that are needed to support species and which have ecological connections between them that enable species, or at least their genes, to move. The report suggested a simple mantra - that we need **more** sites and that these sites should be **bigger**, **better quality** and more **connected** and should be buffered from external pressures.

We need **More** sites because our current network is neither sufficient nor representative enough to protect our range of species and habitats adequately (Shwartz *et al.* 2017). **Bigger core sites** help to ensure that species have sufficient habitat and habitat diversity for their needs. **Bigger** sites, along with associated buffer zones, can reduce the impact of outside pressures and provide better environmental conditions for nature through making space for natural processes and dynamism. Many sites are currently in a degraded condition, so it is important to make such sites **Better** to improve habitat quality, with more variation in vegetation structure to accommodate more species and help them cope with pressures such as climate change. Finally, we need to improve **Connectivity**, sometimes through the provision of 'stepping stones' and habitat corridors in the landscape, to increase the chances for species to disperse between habitat patches and colonise new ones. These principles have been applied successfully through the setting up and delivery of a pilot suite of Nature Improvement Areas in England (Collingwood Environmental Planning 2015).

While these are excellent guidelines, conservationists in the field, or those delivering landscape scale conservation initiatives with stakeholders, need to know more about how to put this into practice in a particular place (Isaac *et al*. 2018).

For example

- How *big* do we need those sites and habitat patches to be?
- How do we make them '*better*' to retain their present interest and prepare them for new arrivals?
- How many *more* do we need and where should they be placed?
- What sort of *connectivity* is best?
- How do we *buffer* them from outside pressures most effectively?

Furthermore, conservationists need to balance a whole set of objectives for a wildlife site or a landscape – not just for wildlife, but also for the needs of the local communities and the ecosystem services provided to society. In addition there are demands of land for agriculture, industry, energy production, water storage, flood alleviation and other factors that need to be accommodated – this is what makes a Nature Network.

1.2 Principles for creating networks for wildlife and people

In order to develop a nature network, it is important to consider *how* the network should be created, not just the physical design on the ground. This section sets out underlying principles and the evidence behind them. The technical design – the *what* – is the subject of Chapter 2.

To be successful, the planning of nature networks should aim to work with the ecology, landscape and people living within that landscape. This will be essential not only for providing resilient habitat networks for species, but also more robust and valued landscapes for people, where natural capital[1] and the benefits of ecosystem services are recognised, valued and invested in, over the long term.

[1] Natural capital is defined as the elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions (Natural Capital Committee 2017).

The following 10 principles provide a summary of how to design nature networks in an integrated way, to benefit biodiversity and people. These principles are consistent with, and informed by both the Ecosystem Approach[2] and the European Landscape Convention[3].

1.2.1 Key Principles for Nature Networks for wildlife and people.

1. **Understand the place: Recognise where the nature network will sit,** in terms of how the natural characteristics of the area generate conditions for different habitats and how the cultural landscape character has evolved and is valued. Identify what the area is special for, from a national and local perspective, how nature has changed and the potential for its restoration. This assessment should include biodiversity and ecosystem function, geodiversity, landscape and the historical environment. Understand where people live and work and how ecosystems provide benefits to them. This enables us to identify priorities and opportunities, and to be sympathetic to the current character of the landscape, while not being constrained from accommodating what the future might hold.
2. **Create a vision: for your nature network and be clear about your objectives**: specify what the ultimate goals are for the network, identify the spatial scale, and the environmental and societal aspects that are important.
3. **Involve people: People both benefit from and create nature networks:** plans should engage and be created with the community; recognising that the landscapes and the ecosystems that support species, also provide **multiple benefits** to people.
4. **Create core sites:** Core sites are the heart of nature networks; these are places that sustain thriving wildlife populations that may expand across the network. It will often be best to **build core areas of nature networks by enlarging, connecting and improving existing high quality wildlife sites,** to make well-functioning ecosystems. However, on occasion, it will be appropriate to fill gaps in a network by creating core sites where little wildlife currently remains. Within landscapes, working with **functional ecological units** will provide the building blocks to support abundant and diverse wildlife and ecosystem services.
5. **Build resilience: Enhance the resilience** of landscapes, ecosystems and their ecosystem services through **restoration that reinstates natural processes,** accommodates desirable change, improves low quality habitat and includes areas that provide buffering from the causes of current and potential future environmental degradation**.** Take opportunities to deliver nature-based solutions to climate change and reduce external pressures (such as diffuse pollution).
6. **Embrace dynamism:** Remember that in a natural state, **ecosystems and landscapes change and are inherently dynamic over short and long time scales;** allow natural processes to

[2] In 2000 the Convention on Biological Diversity adopted the Ecosystem Approach to address the needs of both biodiversity and society: '*The Ecosystem Approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. It is based on the application of scientific methodologies focused on levels of biological organization which encompass the essential processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of ecosystems.*' https://www.cbd.int/decision/cop/default.shtml?id=7148

[3] The UK Government is a signatory to the Council of Europe's European Landscape Convention (Council of Europe 2000). The ELC stresses that landscape is central to people lives, not as just scenery, but because it links culture with nature, and past with present. It is forward looking in its measures and recognises the dynamic nature of landscape – with an emphasis on management of change and the creation of new landscapes that reinforce our identity and relationship with place.

operate whenever possible, as they will aid restoration of ecosystem function and enhance the sustainability of conservation efforts.

7. **Encourage diversity**: Nature networks need to include **a diverse physical structure,** influenced by the underlying geodiversity, to accommodate the widest variety of opportunities (niches) for species. Biological **complexity and landscape diversity** are important to facilitate resilience. Such diversity is best founded on the restoration of natural environmental processes where this is possible, overlain by vegetation management regimes that encourage further diversity.
8. **Think 'networks':** Networks need to be **planned at multiple spatial scales and address multiple issues.** Joined-up actions across adjacent landscapes help to deliver integrated outcomes and ensure that the network acts as a coherent whole for all species (especially for those that live in the wider countryside), ecosystems and people within the area.
9. **Start now but plan long-term:** Identify the locations that can deliver a coherent nature network, but prioritise those locations that provide the best opportunities **for action now,** while developing longer term solutions.
10. **Monitor progress: evaluate actions** and **adapt management** in the light of results, to achieve long-term aims at local and national scales.

The evidence underpinning the key features of each of these principles are in Appendix 1.

1.3 Participatory engagement in nature network design

To help put people at the heart of the environment and create shared plans for places there are a range of participatory tools and approaches that can be used (e.g. Porter *et al.* 2012). These can be used to engage local communities in the process of understanding, and making choices, about the future resilience of their local landscapes and how nature networks contribute to this resilience.

Having a voice in the community and feeling a sense of empowerment gives citizens a stronger commitment to their local area (Brodie *et al*. 2009). As a consequence they will be more likely to contribute to local activities and participate in the longer-term care and investment in a place. People engage when they think that they will be listened to and when their actions may be able to improve the area and their own lives, and tend to disengage when they don't. If there is a track record of positive engagement, then this helps to build a positive feedback loop which encourages further participation.

When done well, community engagement can bring a wide range of benefits, as well as social learning and producing behavioural change for those involved in a particular project or plan. It can build trust in, and improve the reputation of, the conservation sector and deliver improvements to landscapes, habitats and ecosystem services. Involving people in decisions about their local environment can also strengthen a sense of community and provide significant benefits to health and well-being.

1.3.1 A Collaborative approach

The purpose of a collaborative approach is to achieve a more efficient use of resources and to gain knowledge and expertise from different sectors. It can also help in understanding the motivations of the people involved, so helping to build better community relationships and a long term commitment. This is achieved through agreeing joint goals and aspirations, for the near future and long-term, for the place in question.

It is important that those working on the project are clear at the outset about the project goals, the aims of community engagement and both short and long term outcomes. Planning community engagement should involve:

- **purpose** - be clear about what the engagement activity seeks to achieve;
- **context** - pay attention to the needs and character of the local community while bearing in mind the wider contribution which the area can make to help realise national ambitions for ecosystems, habitats and species;
- **people** - consider who should be involved, what their needs are, and what support or incentives may help them take part;
- **method** - design the process and choose a method that is appropriate to the purpose, context and people; and
- **outcome –** agree the goals and overall objectives.

Establishing a clear purpose for the engagement activity, and securing agreement from partners, is critical because it will serve as a reference point throughout the project. A common criticism of engagement is that consultation is tokenistic. Being clear what the objectives are, how they will be achieved and how partners will know whether objectives and goals have been met, can help avoid this.

1.3.2 Building a vision

When designing nature networks it is important to establish, early on, a broader vision for the area which aims to create a healthier, wildlife-rich and more pleasant and beautiful place in which to live. A landscape-scale vision can set out the intention of how we bring together the landscape context, with ecosystem services and access considerations as part of an overall nature network.

Participatory design offers powerful ways to develop a vision for an area, not only to engage people and enhance people's awareness of landscape and ecological change, but also to seek opportunities and agree design solutions that are of environmental, socio-cultural and economic value. An example of a participatory approach is the use of design 'charrettes', which are intensive planning sessions where citizens, designers and others, collaborate on a vision for development (Sutton & Kemp 2006). They provide a forum for ideas and offer the advantage of giving immediate feedback to the designers. More importantly, it allows everyone who participates to be a mutual author of the plan.

A good illustration of this at work can be seen in development of the North Devon Nature Improvement Area (NIAs were a government initiative to encourage landscape scale conservation by groups of local stakeholders) (Inwood *et al.* 2015). A key objective of the NIA was to improve landscape resilience (Devon Wildlife Trust 2015), but this requires the consideration of a range of interconnected physical, ecological and cultural processes that exist in a place. Thus the North Devon NIA team brought together information on issues such as ecology, agriculture, climate change, community and social resilience and conservation of the historical environment. The views of the general public were sought at an early stage in the process, and with a particular focus on cultural services (e.g. spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences; Fish *et al.* 2016). It was found that the design of the NIA benefitted through the inspiration, background knowledge and expertise of the local population. One additional major benefit of participatory engagement in landscape planning is that local people can learn a great deal about their surrounding environment and the potential for change, which in itself can lead to further engagement.

1.3.3 Who to involve?

Stakeholders are those who feel that they have an interest in the issue or place, either because they are likely to be affected by the project's outcome, benefit from ecosystem services or because they are able to influence key decisions. They include wildlife site owners and other organisations or individuals, who either live close to a site or visit regularly (e.g. tourists, dog walkers). When embarking on a project to design a nature network it will be useful to undertake a stakeholder analysis (Mushove & Vogel 2005) to produce a 'stakeholder map' and engagement plan.

A stakeholder 'map' is a diagram that shows the informal and formal networks, groups and activities that exist in a community (e.g. Vance-Borland & Holley 2011). This will enable you to get involved with key groups. If you can do so, identify who the community catalysts are, the people who are already active in a community and who are instrumental in motivating, organising and bringing people together. Learn from their experience, local knowledge and the role that they play within local networks.

Mapping who is benefiting from a range of ecosystem services, and where they are benefitting, may also help to identify who to involve. Some of these beneficiaries may be located at a distance from an area of conservation action, e.g. where upland areas supply water to urban areas, or are managed to reduce downstream flood risk. Decisions will need to be made about whether to involve distant beneficiaries, who to involve and how.

However, bear in mind that in any area only a minority of the population will be active within the community. The 'silent majority' also has views and opinions which may emerge through consultation; these views need to be balanced with those of the more active citizens. Do not exclude those known for their opposition: instead try to engage them constructively. You will be judged by other stakeholders on how well you handle opposition: handle opposition with care, honesty and integrity. See Box 1.3.3 for a simple analysis or map of stakeholders.

Box 1.3.3 An example of the types of stakeholders to include in a stakeholder map

Stakeholder maps should include:

- politicians in the area (local and national);
- environmental groups
- local naturalists
- countryside-access user groups
- private sector businesses, especially those who might be prepared to support activity
- local authority stakeholders
- parish councils
- local media
- developers (who might access Community Infrastructure Levy)
- landowners, including farmers and land managers
- local resident groups.

1.3.4 Scope and Types of Engagement

The International Association for Public Participation has developed a framework for understanding the depth and scope of engagement (see Table 1.3.4). This is based on five levels of engagement, each one with increasing levels of participation and involvement. At one end of the spectrum, engagement is simply an information-sharing exercise, for example through the provision of websites (e.g. MAGIC[4]) or newsletters. At the other end, engagement can lead to genuine community empowerment and local control. More and deeper engagement is likely to lead to more successful outcomes, but the level of engagement for any particular aspect of a project will need to be considered with respect to the benefits to be achieved, as deeper engagement can be costly in terms of human resources.

Table 1.3.4 Types of public engagement, based on International Association for Public Participation framework (see Brodie *et al*. 2009, Studd 2002)

	Objective	**Practice**	**Method examples**
Inform	Provide information about the project and plans	One-way information dissemination to the public	Fact sheets or newsletters Websites Exhibitions
Consult	Inform and seek public feedback	Two-way information flow, invite responses and consider them in decision making	Public meetings Website surveys Email questionnaires
Involve	Work with the public to provide an iterative process of information and consultation	Work with the public to consider how responses to iterative consultation should be considered	Consensus building workshops
Collaborate	To develop partnerships with the public or its representatives, but decisions are ultimately made by the project group	Seek help from public and its representatives in joint working to develop mutually agreeable solutions	Advisory committees
Empower	To develop solutions together, and put power of decision-making in hands of the public	Build capacity with the public or amongst their representatives to take ownership of the project	Support local authority decision makers Community Trusts Grants and skills provision

[4] http://magic.defra.gov.uk/

2 Developing a plan for a nature network

Summary

- When developing a plan to implement a nature network, having agreed a vision for the network with stakeholders, it is important to consider the constraints and opportunities provided by the landscape, geology, soils and ecosystems within the landscape, the need to build resilience to climate change and land ownership.

- The socio-cultural context of the area will help to identify constraints and opportunities based on the potential for a nature network to provide enhanced and additional services to local and wider communities, particularly with regard to access to the countryside.

- We provide a suite of ecological rules of thumb to aid practitioners, based on a detailed review of the ecological requirements for a nature network. This identifies that the hierarchy of priority actions are to (a) improve core wildlife sites; (b) increase the size of core sites; (c) increase the number of core sites; (d) improve the 'permeability' of the surrounding landscape for the movement of wildlife; and (e) create corridors of connecting habitat.

2.1 Introduction

Having engaged with local stakeholders to agree upon a vision for a nature network, the next stage is to consider how to plan this on the ground and who owns the land. This involves considering in more detail the landscape and geography of the area, its geology and soils, how to improve resilience to factors that might be affecting the environment and wildlife detrimentally, and the ways in which society might benefit from an improved nature network.

Given that a fundamental aspect of designing a nature network is to generate a landscape that has an abundance of wildlife, we provide some detail on the ecological aspects of network design. We have summarised these as a suite of rules of thumb to aid practitioners, but also review the evidence that underpins these rules and highlight where evidence is lacking.

2.2 Initial considerations: Landscapes, ecosystems and resilience

2.2.1 Landscapes

These are a result of the way that different components of our environment – both natural and cultural – interact and are perceived by us (Fig. 2.2.1). The European Landscape Convention (ELC; Council of Europe 2000) describes landscape as:

> '*an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors*'.

As such, they encapsulate the natural beauty that people treasure and that nature networks should seek to enhance. This is not about preserving landscapes in aspic, but rather to understand how people perceive and value the landscape and to facilitate local support for the changes that establishing a nature network may involve.

Landscape can also be thought of as a socio-ecological system (Petrosillo *et al.* 2015; Young *et al*. 2006) – where ecological and socio-cultural processes interact. Understanding what people value about a landscape will help to ensure that nature networks are designed to provide benefits to society, and are therefore acceptable to local populations (Inwood *et al.* 2011, 2015, in press). For example, the Cheshire ECOnet Life project used the distinctive landscape features of the mid-Cheshire sandstone ridge (Natural England 2014) to focus conservation delivery, working with the Sandstone Ridge Trust[4]. The project also engaged closely with local community groups, parish councils, and environmental charities, supporting 33 projects proposed by these groups which enabled local people to become involved, enjoy their local countryside and enhance its wildlife (Sandstone Ridge ECOnet Partnership 2009).

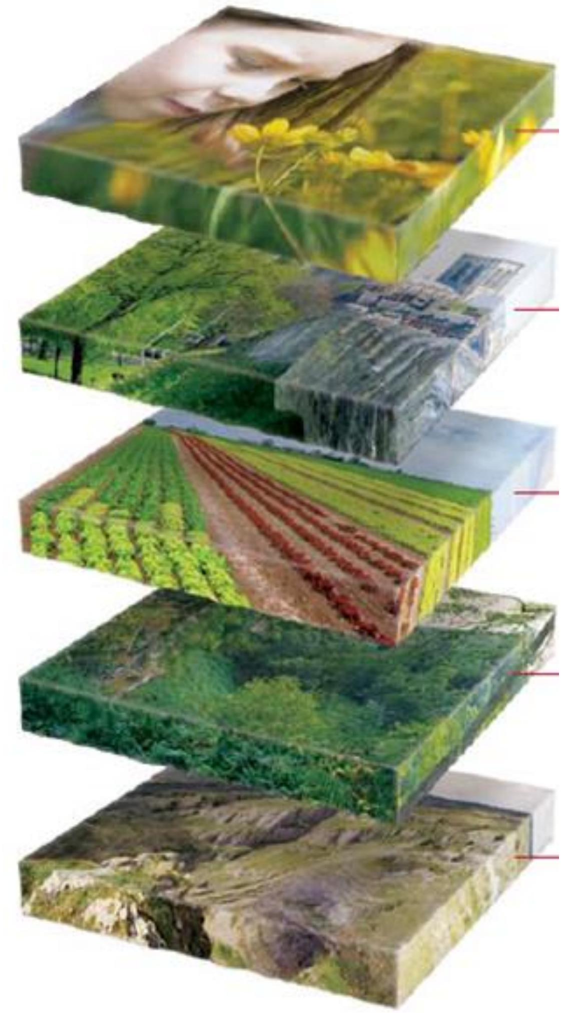
To safeguard and enhance the beauty of our natural scenery and improve its environmental value, we need to be able to identify the key features of landscape that contribute to its character and beauty. Key tools that are available to help with this are described in Natural England's *Summary of Evidence: Landscape* (Bolton 2015) and include:

- the **National Character Area (NCA) profiles** produced by Natural England[5]. These provide descriptions for 159 areas of different landscape characteristics in England (and which follow natural lines in the landscape rather than administrative boundaries). Each profile includes a description of the natural and anthropogenic drivers for ongoing change, a broad analysis of each area's characteristics and ecosystem services, and an integrated Statement of Environmental Opportunity that informs where environmental gains may be delivered. Through analysis of key attributes and ecosystem services in the NCA profiles, the conservation and enhancement of distinctive landscape characteristics can be aligned with the management of ecosystem functions.

- **Landscape character assessment** (LCA) is the process of identifying and describing variation in character of a landscape (see Box 2.2.1). It explains the unique combination of elements and features that make a landscape distinctive, by mapping and describing character types and areas. LCAs provide the opportunity to look at the structure, pattern and process of ecological systems and more clearly communicate how they influence landscape character, and, equally, how patterns of landscape character can be reinforced through the restoration of ecological functions. LCAs also show how the landscape is perceived, experienced and valued by people (Tudor 2014).

[4] see http://www.sandstoneridge.org.uk/ (Accessed 3/2/19)

[5] https://www.gov.uk/government/publications/national-character-area-profiles-data-for-local-decision-making/national-character-area-profiles (Accessed 3/2/19)



Experience: landscape is more than the sum of physical features that make up our environment. How we perceive the landscape can have an important influence on how we use or value its character and resources.

History: all landscapes in England have been shaped by human activity throughout history. It is therefore important to understand past land use patterns, the extent to which they have survived and how different stages have contributed to the character of today's landscape.

Land use: includes all the various uses that people make of the landscape such as settlement, farming and field enclosure, energy production and forestry. The character of the landscape is particularly influenced by the present day pattern of these features as well as their historical legacy.

Biodiversity: the variety of plants and animals in the English landscape has influenced and been influenced by us over thousands of years. The types and abundance of wildlife can play a significant role in shaping the character - and in some cases the function - of each particular landscape.

Geodiversity: includes the diversity of rocks, minerals, fossils, landforms, processes and soils. Underlying geodiversity and natural processes such as weathering, erosion and deposition define and shape the character and functioning of our surrounding natural environment and landscapes. Geodiversity directly influences the distribution of habitats, land use and settlement patterns, and our wider experience of the natural world.

Figure 2.2.1 The different components that make up a landscape

Box 2.2.1 Landscape Character Assessments

Landscape Character Assessment (LCA) is useful in understanding the character of a place and can aid nature network design at all spatial scales. LCAs are put together from a baseline analysis of the components that influence and shape the landscape and can help in linking up landscape and ecological objectives which benefit wildlife and people:

1. LCAs provide a spatial analysis of key landscape structures, patterns and features that define the distinctive landscape character of an area, and those that may also support particular underlying ecological functions.

2. They identify where the structures, patterns and features that define landscape character are becoming fragmented or of poor quality or condition, for example – this may also help point to where there are opportunities for habitat connectivity and restoration.

3. They can be used to recognize opportunities to create and evolve landscape character through creation of new habitat and enhanced ecosystem function.

4. They identify what is characteristic in an area and contributes to aesthetic qualities, sense of place or cultural heritage and identity. This information will support participatory approaches and engagement with local communities in nature network planning and design process and valuable in gaining support where there could be potential changes in landscape character (Inwood *et al.* 2015, in press).

2.2.2 Geodiversity and soils

Geodiversity is a defining part of the natural world. It represents the diversity of rocks, minerals, fossils, landforms, geomorphological processes and soils which collectively underpin the way our landscapes look, and defines how the natural environment functions (Gray *et* al. 2013). Geodiversity is an important part of a nature network as it has a direct influence on the diversity of habitats and species, is a natural capital asset and provides a range of natural processes essential to functioning ecosystems, and wider ecosystem services that include carbon capture and natural flood regulation. Geological archives tell us how the natural environment and the ecosystem services it provides has changed over time (e.g. Jeffers *et al.* 2015).A Nature Network should both conserve and recover geodiversity and, in so doing, seek opportunities that benefit both biodiversity and landscape.

Geodiversity helps us better understand how a nature network operates. For example, interpreting the evidence from past environments in the geological record leads to a better understanding of environmental change and response today, and into the future (Willis *et al.* 2010). Maintaining and enhancing the geodiversity of a nature network is important as it ensures access to this past record and maintains the landscape character of the network. There are other important benefits of integrating geodiversity into planning, building and implementing a nature network. As well as provision of essential natural processes, maintaining a range of geodiversity (including both natural and man-made outcrops and exposures) enhances both habitat and species diversity (Beier *et al*. 2015) and is an important contributor to the principles of making sites better, bigger, and in particular, more connected within the nature network (Lawton *et al.* 2010). Geodiversity also provides a means of connecting past, present and future within a landscape and can be used to connect people with nature through building their understanding of environmental change using geological evidence of past flooding, climate change and adaption, and through making links between geodiversity and cultural heritage, for example through historical exploitation of mineral resources.

There is an intimate relationship between geodiversity and the overlying association of substrate, soil, habitat and species (Hopkins, 2003; English Nature, 2004). At a broad level chalk and limestone produce alkaline, well-drained soil (for example the Downs and Wolds), sandstones, sands and gravels lead to acidic, well-drained soil (for example the Purbeck Heaths), while finer grained rocks such as clay, mudstone and shales have poorly drained soil (for example the heavy clay soils of the Weald). Each have a characteristic flora and fauna, for example, chalk Downs and Wolds support a flora dominated by deep rooted, low-growing plants adapted to calcareous, arid and nutrient deficient conditions (e.g. autumn gentian and the hairy violet).

There are very specific relationships, for example the direct link between exposed rock surfaces and lichens, and rare metallophyte plants growing on mine dump spoil. There are also other ecological relationships, such as the benefit that bare ground and rock surfaces bring to a range of invertebrates or simply as nesting sites for birds.

Geodiversity and geoconservation therefore benefit biodiversity in a number of ways, including:

- Understanding geodiversity helps better understand biodiversity and guide the decisions made in managing biodiversity.

- For coastal and river environments the best geodiversity management is to maintain natural processes. This non-intervention maintains a natural range of fresh rock exposure and will also maintain a natural habitat succession.

- For inland geodiversity typically geoconservation involves the removal and redistribution of scree and clearing vegetation which provides a mix of bare rock, open ground and habitat mosaic (benefiting both geodiversity and biodiversity).

- Disused quarries and pits (valued for their geodiversity) often provide a refuge and diversity of habitat for both non-specialist and specialist species which is reflected in the large number of these sites that are managed for their biodiversity.

It is therefore important when planning, designing and delivering a Nature Network that they deliver outcomes for geodiversity, and seek the mutually beneficial opportunities that come from managing geodiversity and biodiversity together.

Soils form as a result of the interaction between the underlying geology, and the vegetation and its decomposing organic matter. They are good markers of previous habitats and land use, and help to define what ecosystems can be restored. As soils develop structure, they carry out complex interactive processes, mediated by soil organisms, including cycling of carbon, fixation of nitrogen, and mediating the flow and quality of water. These processes are fundamental to many ecosystems, their services and most land use activities. Soils are diverse in their structure and function and have been categorized by the properties of soil layers (known as horizons) and by the nature of the parent material from which they are derived. This diversity reflects differences in soil-forming conditions, but also reflects more recent vegetation and land management that influence both structure and ecosystem functions. A total of 698 soil types (series) have been described for England and Wales (Avery 1980; Clayden & Hollis 1984).

Soils are habitats for many thousands of species, ranging from bacteria, fungi, protozoa, and microscopic invertebrates to mites, springtails, ants, worms and plants. It is estimated that more than 1 in 4 of all living species on earth is a strictly soil-dwelling organism (Decaens *et al.* 2006). Soils are thus an important component of any nature network, in their own rights. However, they can also provide added value to nature networks through their ecosystem services, including water purification, water storage, flood alleviation, carbon storage and growing crops, biofuels and timber.

Thus topography and soil systems are fundamental to the ecology of a landscape, as well as determining what is possible, in terms of agriculture and other land uses. Understanding and working with the geodiversity of an area helps to ensure that nature networks are appropriate and how they can be used to contribute to the provision of geodiversity-based ecological services (such as carbon storage and flood control; Gray *et al*. 2013). Geodiversity also has a major impact in influencing the ecological characteristics of a landscape and species distributions (Anderson *et al*. 2015). It also influences the ability of species to be resilient in the face of climate change, for example through providing climate change refugia (areas where species can persist under climate change: Suggitt *et al*. 2014, 2018).

To better understand geodiversity, and the opportunities that it presents for a nature network, geological and soil maps (available from the British Geological Survey) provide a detailed illustration of the underlying geology and soil type. Designated sites, including geological SSSIs, National Nature Reserves and Local Geological Sites, and internationally important geologically-managed landscapes such UNESCO Global Geoparks and the Jurassic Coast World Heritage Site, are a key resource that should be incorporated into the nature network, and there is a significant geological knowledge (across the geological community, local geological groups and learned societies) that is available to help the successful delivery of a nature network.

2.2.3 Ecosystems

These are defined by the Convention on Biological Diversity (CBD) as:

> '*A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional units*'[6].

Ecosystems can be thought of as an assemblage of living things (biotic), together with their non-living (abiotic) environment. Thus they include soil, water, nutrients, climate and other external factors as well as the vegetation and species present. Defining the boundaries of an ecosystem (functional unit) is not straight forward, as interactions occur over a wide range of spatial scales. For convenience, ecosystems are often delimited according to vegetation or habitat types (woodland, grassland etc.). However, the term ecosystem is used to indicate that it is the system's properties and interactions, including with people, which are the focus of attention. It is just as legitimate to delimit ecosystems according to physical processes, for example catchment or soil boundaries. From this perspective the ecosystem will often operate at a larger scale than a patch of a particular sort of vegetation. When trying to understand ecosystem quality, the functions and functioning (Jax 2010) of the system is often referred to:

- **Ecosystem Functions** are the interactions between biological, geochemical and physical processes and components that occur within an ecosystem.

- **Ecosystem Functioning**, is defined as the network of interacting Ecosystem Functions that determine the operating performance of an ecosystem as a whole. This underpins the capacity of an ecosystem to provide ecosystem services and wider benefits to society. An ecosystem that has poor functioning (referred to as degraded) will no longer be delivering the potential benefits to society.

In England, most ecosystems are semi-natural: they have been subject to human influence for centuries or millennia (Rackham 1986). Conservation recognises 56 habitats as of 'principal importance' for the conservation of biological diversity in England (under section 41 of the Natural Environment and Rural Communities Act 2006). Some of these require nothing or very little in the form of human management, such as coastal vegetated shingle, blanket bog and various types of

[6] https://www.cbd.int/convention/articles/default.shtml?a=cbd-02 (Accessed 3/2/19)

woodland. Others are very clearly dependent on their creation as part of agricultural practices, such as arable field margins, traditional orchards and hedgerows. Many can be maintained through minimal human intervention, except by managing grazing regimes or limiting nutrient inputs, such as calcareous grassland and lowland heathland. **The reinstatement of natural processes** is often a key way to improve ecosystem functioning and reduce the need for human intervention, making sites more sustainable in the long-term (Mainstone *et al*. 2018). There are numerous guides to the management of different habitats, such as those for the restoration and management of lowland heathland (Symes & Day 2003) and the management of fens (McBride *et al*. 2011).More information on these can be found in Chapter 3 and Appendix A3.4.

It is also worth bearing in mind that nature networks can also spread into built up and urban areas, as green infrastructure. There is great scope for helping to bring some, albeit highly human-modified, habitats close to the centres of population, with potentially great benefits for health and well-being and to engender interest in wildlife that can lead to societal support for nature networks more generally (Esteban 2012 & see section 3.2.1).

2.2.4 Resilience, restoration and networks

Our central aim should be to create high-quality and distinctive **resilient landscapes** that have high conservation value for wildlife, where all its attributes are recognised, understood and valued by people. The concept of resilience is central to Natural England's conservation strategy (Natural England, 2016) and the Government's 25 Year Environment Plan (Defra 2018a). Natural England has defined this operationally as:

'Resilient landscapes and seas are capable of absorbing, resisting or recovering from disturbances and damage caused by natural perturbations and human activities, while continuing to meet overall objectives of supporting biodiversity, landscape character, geodiversity and benefits for people. This depends on functioning natural processes and society's support for sustainable management of the natural environment and cultural heritage. There are situations where the best environmental outcome may be to promote or accept change: our overall commitment to resilience is not intended to preclude this.'

This can be summarised as:

> '*Resilient landscapes and seas are able to keep meeting the needs of people and nature in a changing world*'

This definition thereby combines the two common attributes of resilience found in the literature:

1. The amount of disturbance that something can withstand without changing self-organized processes and structures; **or**

2. The ability to return to a stable state following a perturbation.[7]

Building landscape resilience requires us to undertake actions that will enhance the social, ecological, cultural and economic structures and processes that enable the landscape to reorganise following a disturbance (Selman 2012). But to inform management decisions with respect to resilience, there are a series of important questions that need to be considered:

[7] perturbation: change from the normal state caused by some event

- we need to be clear what our conservation assets and goals are, and how they can be made increasingly resilient;

- we need to understand the pressures and threats to our conservation assets to help us tailor our resilience strategies;

- we need to consider over what spatial areas and periods of time we want to maintain resilience;

- we need to consider both the ecological and social aspects of resilience;

and, in achieving our objectives

- we need to decide how much change, and of what kind, is acceptable, or even desirable. Where unstoppable change is inevitable (e.g. sea level rise) this needs to be used to deliver the best possible conservation outcomes in the longer term.

The concept of a *coherent* nature network, in which individual components can provide different and variable contributions at different times while the full range of native national biodiversity is conserved at network level, ensures that conservation outcomes can be sustained and are resilient in the long term, even in the face of inevitable change (Isaac *et al.* 2018). This requires an understanding of the contribution of different parts of the network towards the overall conservation status of particular habitats and species. The concept of Favourable Conservation Status[8] (covering the entire resource inside, as well as outside, protected sites) provides a framework for planning and joining up effort at multiple spatial scales (Jones 2002).

Following on from this, there are four important cross-cutting issues to consider:

- **Accommodating and adapting to change**. A certain amount of change, for example working with an eroding coastline, a naturally evolving river or as a result of long-term climatic change, is fully consistent with taking a resilience approach when considering ecosystem functioning – i.e. the functioning of the whole system (Jax 2010). Resilience does not mean trying to 'set things in stone'. Decisions on the type of change that is appropriate to a location should be informed by an understanding of the natural functioning of the landscape and the best contribution towards network objectives. It is also important that local communities are involved in the decision making process, so contribute to shaping change - as this will help to foster the ability to create and adapt to resilient landscapes in the longer term. Our conservation systems, as well as our economic and social systems, will themselves need to be modified in order to accommodate changes in the natural world, especially as a result of climate change.

- **Working at different spatial scales**. Thinking about resilience at a large spatial scale, planning across networks of sites and habitat patches, will often be as important as planning for resilience at a site scale. It is important to consider the broader context of a site, as well as considering the impact of large scale planning at a site level. This will help to achieve an appropriate balance of the different conservation objectives identified at each scale – for example local nature networks need to be designed in the context of the broader national networks, to ensure coherence at all levels.

[8] http://jncc.defra.gov.uk/page-4096 (Accessed 3/2/19)

- **Joined-up actions across the landscape.** Most elements within a landscape are connected in some way, and these inter-connections will influence the success or failure of conservation action. Thus, conservation and other land uses need to be integrated into place-based solutions that help to enhance one another rather than act antagonistically. Sustainable solutions that enhance social, ecological *and* economic structures and process will deliver greater landscape resilience in the longer term.

- **Ecological restoration.** By 'restoration', we mean both restoring and creating ecosystems that will replace some of the values, benefits and characteristics that have been lost. This should not be an attempt to create a copy of how it might have been at some point in the past, because the world is constantly changing. In this sense, restoration is, above all, about restoring the *quality* of our landscapes and ecosystem functioning, and taking opportunities to create larger areas of semi-natural habitat where natural processes are allowed to operate (Mainstone *et al*. 2018).

Thinking about resilience across landscapes and sets of multiple conservation sites links directly to the idea of '**ecological networks**' (Lawton *et al.* 2010). The ecological network concept has developed primarily from biodiversity conservation, though some definitions also mention ecosystem services to a greater or lesser extent. In this handbook we explicitly broaden the concept of networks to '**nature networks**' that both support resilient and coherent habitat networks for species and landscapes and ecosystems that provide wider benefits and value for people.

2.3 The socio-cultural context for nature network design

Whilst nature desperately needs more 'space' to survive, it is true that people require and value improvement of 'place' (Selman 2012). A better understanding of the human and cultural relationships with our landscapes and ecosystems and what people value (or might value in the future) brings opportunities to design and deliver resilient, useable places for both species and people. To be successful, nature networks should be designed to deliver multiple public benefits and encouraging greater engagement and connection with the natural environment. Furthermore, the strengthening of these connections with people will help to increase the social resilience that is necessary to maintain the ecosystems. People will view the environment as 'on their side' rather than a problem to be solved.

2.3.1 Understanding the socio-cultural context

Nature networks will only be sustained in the longer-term if we engage people in their design and planning and take account of the socio-cultural context of an area. This means understanding the motivations and drivers that affect what people do and what they value. It is people that shape the landscape, manage the land and influence the health of ecological systems and who act to benefit others in their local environment. It is essential to understand local communities and individuals and their social, cultural and economic context if we are to successfully engage people in changes affecting their landscapes and seek opportunities for creating more resilient landscapes. There are a number of data sources (see Box 2.3.1 for examples) that can help to understand the context of the area, particularly Census Data on Population; Multiple Deprivation data; Crime statistics; along with alternative economic indicators beyond GDP such as the Happy Planet Index (Abdallah *et al.* 2009).

Possibly the most useful source of information of how people experience the natural environment in England will be the datasets that have been produced by the Monitor of Engagement with the Natural

Environment (MENE) survey[9]. The main focus of the survey is capturing time spent in the natural environment. It allows us to understand how people use, enjoy and are motivated to protect the natural environment. It also provides data that shows how use of the natural environment has changed since 2009, at a range of different spatial scales and for key groups within the population (Natural England 2019).

Box 2.3.1 Social Data Sources to help understand an area

The UK Census happens every 10 year since 1801 (the last being 2011, the next in 2021). It is a count of all people and households, it provides a detailed picture of the nation, its characteristics, and how we live, so that government can correctly fund public services. It also provides a number of secondary data sets, as well as the population of the area. Households with no permanent residents may suggest dereliction; and health, economic activity and employment statistics can help set social context. *DataShine*[10] is a useful website for accessing and visualising census data, it uses the 2011 Census.

The Index of Multiple Deprivation (IMD)[11] is the official measure of relative deprivation, breaking it down into small areas. This index ranks every area in England from 1 (most deprived area) to 32,844 (least deprived area). The IMD combines information from seven domains to produce an overall relative measure of deprivation, based on the following weights: Income Deprivation (22.5%); Employment Deprivation (22.5%); Education, Skills and Training Deprivation (13.5%); Health Deprivation and Disability (13.5%); Crime (9.3%); Barriers to Housing and Services (9.3%); Living Environment Deprivation (9.3%).

The Consumer Data Research Centre (CDRC)[12] provides access to a range of data sets including IMD, some Census statistics and also a collection of other data sets about urban places including house prices, travel to work, dwelling age, and industry of employment. All of these are useful when investigating quality of life and social context of an area.

Crime: The www.police.uk website (accessed 24/1/19) allows you to search crime statistics for any area of the UK – either by postcode search, or you can define your own search area. You can download a spreadsheet of crimes which can be added to ArcGIS Online by dragging and dropping the spreadsheet onto a map – allowing you to map crime hotspots.

The Office for National Statistics (ONS)[13] provides many useful national government statistics through graphical and spatial outputs, often on current topics in the news.

[9] https://www.gov.uk/government/collections/monitor-of-engagement-with-the-natural-environment-survey-purpose-and-results (accessed 5/12/19)
[10] http://dclgapps.communities.gov.uk/imd/idmap.html (accessed 24/1/19)
[11] http://dclgapps.communities.gov.uk/imd/idmap.html (accessed 24/1/19)
[12] http://maps.cdrc.ac.uk/ (accessed 24/1/19)
[13] http://visual.ons.gov.uk/

2.3.2 Ecosystem services, natural capital and nature networks

The natural environment, our natural capital, provides a vast range of benefits to people (ecosystem services) in some form or other. The formation of soils, nutrient cycling, the carbon and the water cycles all underpin ecosystem services. Natural physical, chemical and biological processes are closely interrelated but our understanding of their influence on the provision of ecosystem services is generally limited (UK NEA 2011, 2014). However this is an area of active research, with recent papers reviewing the relationship between attributes of natural capital and ecosystem services (Harrison *et al*. 2014, Smith *et al.* 2017).

Natural England's report on *Natural Capital Indicators: for defining and measuring change in natural capital* (Lusardi et al 2018) identifies the properties of the environment which are important for the provision of multiple wellbeing benefits, based on the quantity (extent), quality (condition) and location of ecosystems and an example of how to use natural capital indicators on National nature reserves is shown by Sunderland *et al.* (2020) (Fig. 2.3.2.1).

The quantity, quality and spatial configuration of natural capital affects the provision of ecosystem services they provide. For example, different ecosystem extents, conditions and locations are needed for flood regulation compared with recreational access. However, in a *place*, we are looking to design nature networks that work not only for a range of species, but also provide multiple benefits to people. Therefore all the multiple requirements of species and ecosystem services need to be considered in network design.

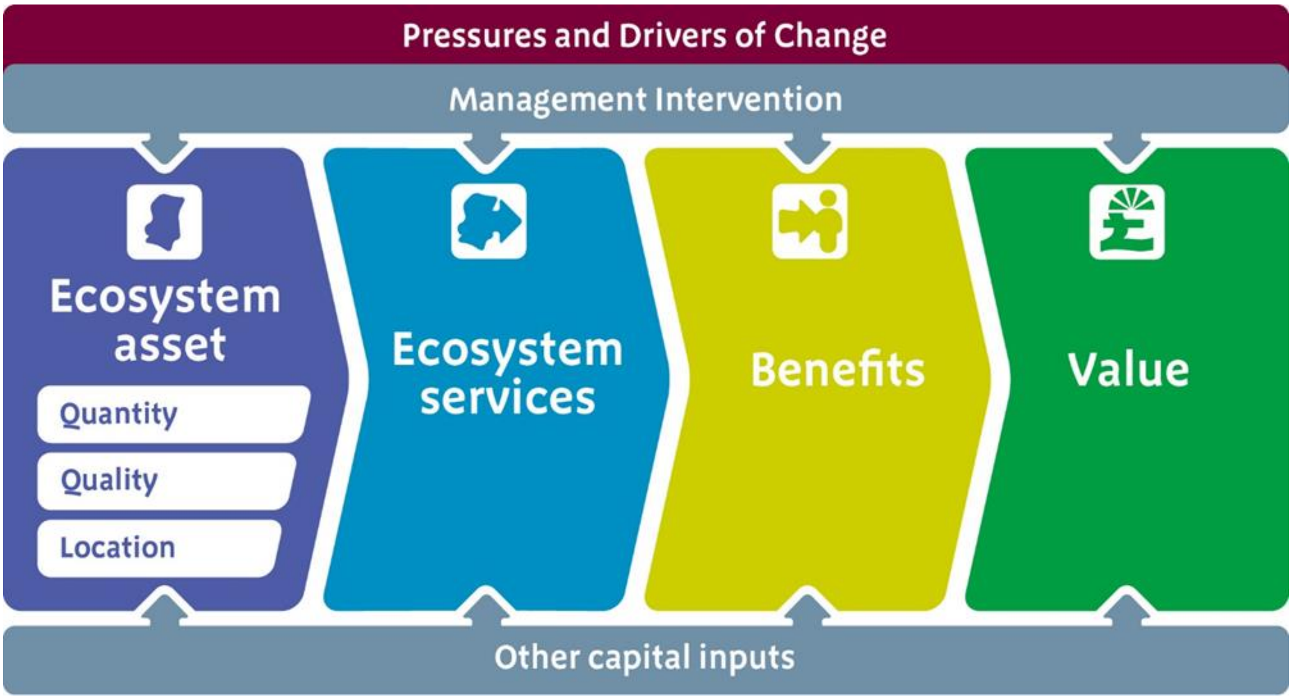


Figure 2.3.2.1 Logic chain diagram showing the link between ecosystem quantity, quality and location and the provision of ecosystem services, benefits and value (from Sunderland *et al.* 2020)

2.3.2.1 *Ecosystem Extent (Quantity):* The UK National Ecosystem Assessment (UK NEA 2011) analysed the potential provision of ecosystem services from a range of broad habitat types and the drivers of change affecting these. Examples of habitat which are particularly important for the provision of multiple ecosystem services, include blanket bog and other upland habitats, coastal & marine habitats, woodland, heath, semi-natural grassland, freshwaters, wetlands, urban blue and green space.

How much of each habitat type is needed in a particular place. This needs to be determined through local decision making. This should take account of the range of benefits that are sought, local demand and the current distribution of benefits across society. This adds an extra dimension to considerations of the habitat extent needed for wildlife.

2.3.2.2 *Ecosystem Condition (Quality):* Improving ecosystem condition is not only beneficial for nature but also for the ecosystem services they provide to people. Natural England's Natural Capital Indicators Project (Lusardi *et al.* 2018) has identified the attributes of ecosystem condition and quality that are important for the provision of multiple ecosystem services (see Fig. 2.3.2.2):

- **Hydrology & geomorphology**: e.g. Naturalness of water levels, flows, flooding, aquifer function, lake hydrological regime, and extent of artificial drainage.
- **Nutrient and chemical status:** of water, soil, sediment, air and of atmospheric deposition.
- **Soil and sediment**: e.g. organic carbon, biota, peat depth, coastal sediment supply.
- **Species composition**: e.g. naturalness of biological assemblage (number of trophic levels and community composition in each), absence of invasive non-native species, frequency and abundance of pollinator food plants.
- **Vegetation**: e.g. proportion of bare ground, plant growth rate, surface vegetation roughness (i.e. structure of the habitat – tussocky grass being rougher than closely-grazed sward), proportion of peat mass actively forming peat, vegetation structure and structural diversity, extent and condition of linear features and of pockets of semi-natural vegetation (in farmland) and vegetation next to water courses.
- **Cultural**: e.g. accessibility, historical environment, landscape, geodiversity, biodiversity, quietness, facilities.

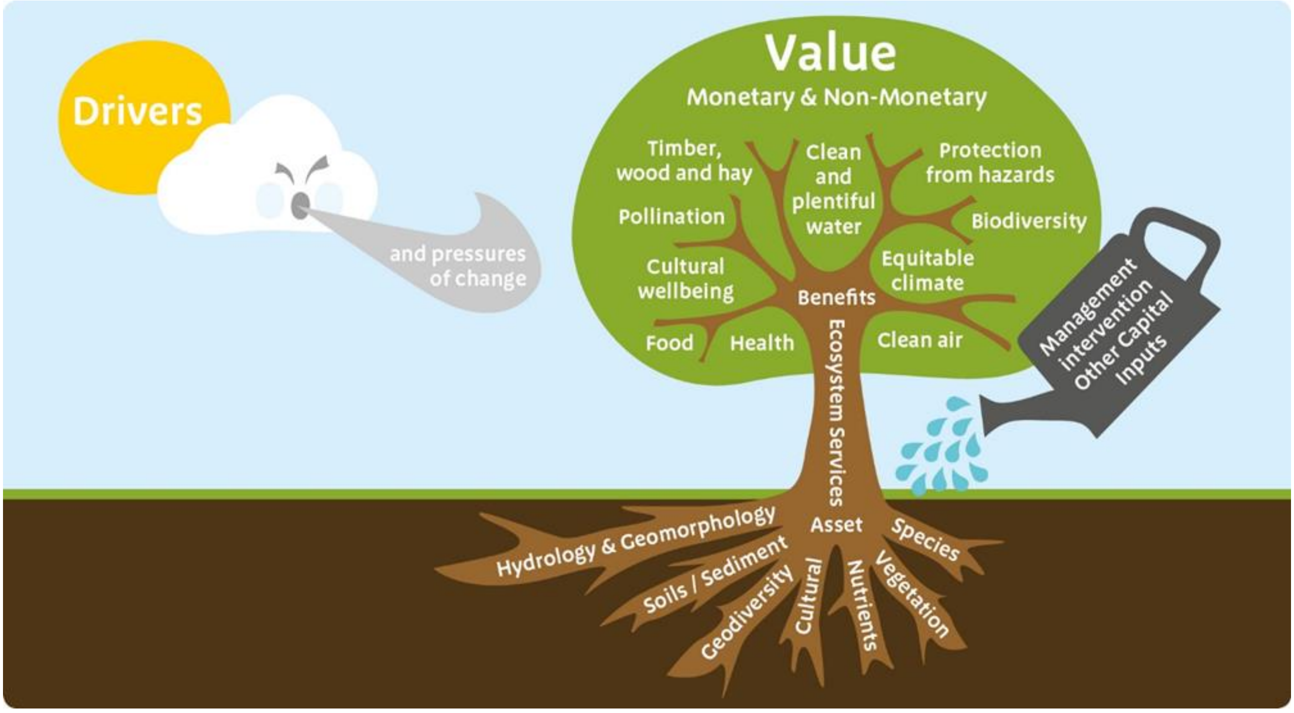


Figure 2.3.2.2 Ecosystem attributes underpinning the provision of multiple benefits (from Sunderland *et al.* 2020)

2.3.2.3 ***Ecosystem Location:*** Where the natural environment is located, in relation to where people are, matters because it will change the amount and type of benefits that people receive. Climate regulation through carbon storage and greenhouse gas fluxes provides benefits to people all around the world. But benefits such as recreation are dependent on the proximity of people to enjoy them. Other ecosystem services such as flood regulation only occur if the management of ecosystems is in the right place.

The following are examples of habitat location factors, for ecosystem services, that should be taken into account in nature network design, to provide multiple benefits for people:

- **Flood regulation:** the distribution (and width for coastal habitats) of flood mitigating land and features in relation to infrastructure & settlements.
- **Water quality:** habitat distribution in relation to water pollution sources, pathways of water movement and receptor areas, where nutrients end up.
- **Substrate stabilisation and erosion control:** the location of habitats and boundary features in relation to soil erosion and landslip risk, and for coastal habitats the width, area and location to allow dynamic movement e.g. of dunes of saltmarsh.
- **Air quality and Noise regulation:** distribution of habitats and trees in relation to buildings and transport routes.
- **Local climate regulation:** position of habitats and trees to provide cooling to buildings.
- **Pollination:** proximity to other semi-natural habitats and insect pollinated crops.
- **Nursery populations and habitats:** naturalness of habitat distributions allowing for dynamic movement of habitats (including transitions from marine to terrestrial); patch size, shape and edge; proximity to other semi-natural habitats.
- **Cultural services:** the proximity and accessibility of land in relation to settlements.

As a society it is very apparent that an adoption of a more active lifestyle, more sustainable travel (walking, cycling etc.) will be beneficial for our health. The provision of greater opportunities with easily accessible green routes and green spaces will very much benefit all parts of society. Further, the link between social deprivation and the lack of nature, and the benefits it provides, have been highlighted in a number of studies, particularly relating to mental health (Esteban 2012, Seymour 2016, Gelsthorpe 2017).

Raising awareness of the locations that are sources of ecosystem services and where they are used, and putting in place delivery mechanisms to rehabilitate these areas, will both prevent further degradation and lead to clearer decision making to improve these areas. With careful design, nature networks will not only benefit wildlife, but also help to improve access to the benefits that can be derived from the natural environment across all sectors of society.

The value (both monetary and non-monetary) of ecosystem services provided, depends both on the amount of service provided and on the number of people that receive the benefit. For example, modelling of the optimal positioning of forest for the Government's forestry target shows that forests close to centres of human population provides far more value for money to the public purse than placing them far from anyone, where land is cheapest (Bateman *et al.* 2014). This is because recreational values increase when woodland is located closer to people, and the costs of greenhouse gas emissions can be reduced by avoiding high carbon soils, such as peat and bog in the uplands. However to deliver such value, forestry has to facilitate public access and be designed to meet people's needs.

A place-based assessment of ecosystem services may provide a more holistic understanding of ecosystem services benefits from a place and how they relate to people (Potschin & Haines-Young 2013). The *Ecosystem Approach Handbook* (Porter *et al*. 2014), provides a useful step by step guide to planning for the provision of multiple ecosystem services by landscape scale partnerships.

2.3.2.4 *Including all values:* Valuing nature's benefits has been growing in importance**,** not just in the UK (e.g. UK NEA, 2011, 2014) but also internationally (e.g. TEEB 2010). But it is much easier to place economic values on some benefits provided by the environment than others. Decision-making should aim to include all economic values, even those which are hard to quantify. Thus, it is important to include 'non-use values' (i.e. the value placed on the existence of species and landscapes irrespective of their usefulness to those interviewed) as well as benefits that are difficult or impossible to quantify economically (such as spiritual access to nature, or personal and cultural attachments to particular landscapes and associated wellbeing benefits) in any decision making (Rolls & Sunderland 2014).

Intrinsic value is the value of nature for its own sake, regardless of the benefits it provides to people. Since its early days, nature conservation in the UK has been built on the notion of the intrinsic value of nature. This is why the Government's 25 Year Environmental Plan (Defra 2018a) says:

'Respecting nature's intrinsic value, and the value of all life, is critical to our mission. For this reason we safeguard cherished landscapes from economic exploitation, protect the welfare of sentient animals and strive to preserve endangered woodland and plant life, not to mention the greening of our urban environments.'

2.3.3 Access for people

An important statutory duty, under the NERC Act 2006, is to promote public enjoyment of the natural environment, as well as equal access to it. People need opportunities to enjoy the benefits of the natural environment through recreation and active travel. Nature networks can provide these if carefully planned from the beginning. Considering access for people at the design stage can help build support for environmental improvements and landscape change. It can also help avoid potential conflicts between access and conservation in sensitive locations.

Considering the geodiversity and landscape character of an area can help create better access routes along features such as rock outcrops or rivers. Early considerations can make them more sensitive to the landform and existing natural environment assets, improve their long term resilience, reduce negative impacts and reduce maintenance requirements, for example, by creating them on robust soil types and rock sections.

We can also better integrate well-designed access provisions into nature networks, by understanding how to meet the needs of users while avoiding areas that do not presently cope well with recreational pressure. For example, well maintained paths and open areas with good infrastructure provision (car parks, disabled facilities, toilets etc.) encourage relatively high flows of people and can be sited in areas that are naturally beautiful but relatively insensitive to disturbance.

All those who manage facilities that are open to the public have a duty under the Equality Act 2010, to take reasonable steps to address the needs of people with a protected characteristic (protected characteristics include aspects such as age, disability and ethnic origin). This includes providing opportunities to access the natural environment for all in wheelchairs, trampers, on bicycles and tricycles, on horseback, in horse drawn vehicles and in some circumstances, in motor vehicles. Whilst this does not mean having to provide for everyone's needs everywhere, current provision is often poor and needs much improvement. More detailed guidance is available in the guide *By All*

Reasonable Means (Countryside Agency 2005) and gaps, gates and styles should conform to British Standards BS 5709:2018.

2.4 Considering nature networks from a species point of view

In this part of the chapter, we are going to discuss the design of nature networks, mainly from the point of view of the species that inhabit these networks.

When thinking about nature networks we need to be aware:

- of the needs of the many individual species that make up those ecosystems as well as the pressures and underlying factors that influence their presence; and

- that ecosystems vary across the country and show varying degrees of dynamism such that although the species make-up on a wildlife site might alter, the overall ecosystem remains essentially the same. For example, a heathland ecosystem in Cornwall will be quite different in species make-up to one in Suffolk, but it will still be heathland. Woodland ecosystems in England are still recognisably woodland despite the loss of Elms in the 1970s due to Dutch Elm disease; and

- that all nature networks sit within a landscape that has had significant loss and degradation of ecosystems that need to be repaired and expanded into the future.

When planning nature networks, it is essential to have clarity about the range of species or suite of species it is intended to support. The need to consider the complete life-cycle of the species, inter-generational aspects and the landscape within which they live helps build this context. Every place is different and needs different components to suit its 'individual personality'.

Lawton *et al.* (2010) defined an ecological network as:

> '*a suite of high quality sites which collectively contain the diversity and area of habitat that are needed to support species and which have ecological connections between them that enable species, or at least their genes, to move*.'

This definition concentrates on the **core sites of highest quality habitats**, which are in best condition and sustainable in the longer term. Many species also use, or have populations in, a wider range of locations and the functional network for any particular species will encompass all such areas, **including the areas within the wider landscape**. Furthermore, the sub-populations within different sites can often be thought of as inter-dependent, being part of the overall 'meta-population'[14] for a species, and thus **sites should not be considered individually**.

[14] A metapopulation occurs in a network of habitat patches containing discrete local populations connected by migration. Some of these populations may go extinct, but the habitat patch will be recolonised by migrants from other nearby patches. Thus not all the habitat patches will be occupied all of the time (Hanski 1998).

Central to the development of a sustainable nature network is the inclusion of **Large Nature Areas** where priority is given to the conservation of biodiversity. These are areas that will provide the sources of biodiversity that brim over into the rest of the nature network, and will provide important areas for ecosystem service provision. Their size and configuration will depend very much on the characteristics of the landscape, its biodiversity and other features. However, we can use the precedent provided by the core areas of Biosphere Reserves in Europe to help provide some indication of the appropriate size, as the core areas are mainly for biodiversity conservation (Ishwaran *et al.* 2008). There are 114 Biosphere reserves in Europe for which information is available[15] (excluding the Russian federation, Belarus and Ukraine which have huge Biosphere reserves) and these revealed that **the median size of a Biosphere Core Area was c. 5,000 ha and the mean size c. 12,000 ha.** So these provide reasonable parameters within which to design Large Nature Areas within nature networks and are relevant to the design of the Nature Recovery Areas proposed as part of Defra's 25 Year Environment Plan (Defra 2018a).

The *Making Space for Nature* report (Lawton *et al*. 2010) identified very clearly that 'coherent and resilient ecological networks' required the pursuit of the four general principles of 'more, bigger, better and joined'. Following Lawton *et al.* we have split 'joined' into two, because evidence suggests that providing 'stepping stones' and improving the 'permeability' of the matrix are usually more important than providing physical corridors through which nature can disperse. Thus the hierarchy of importance should be:

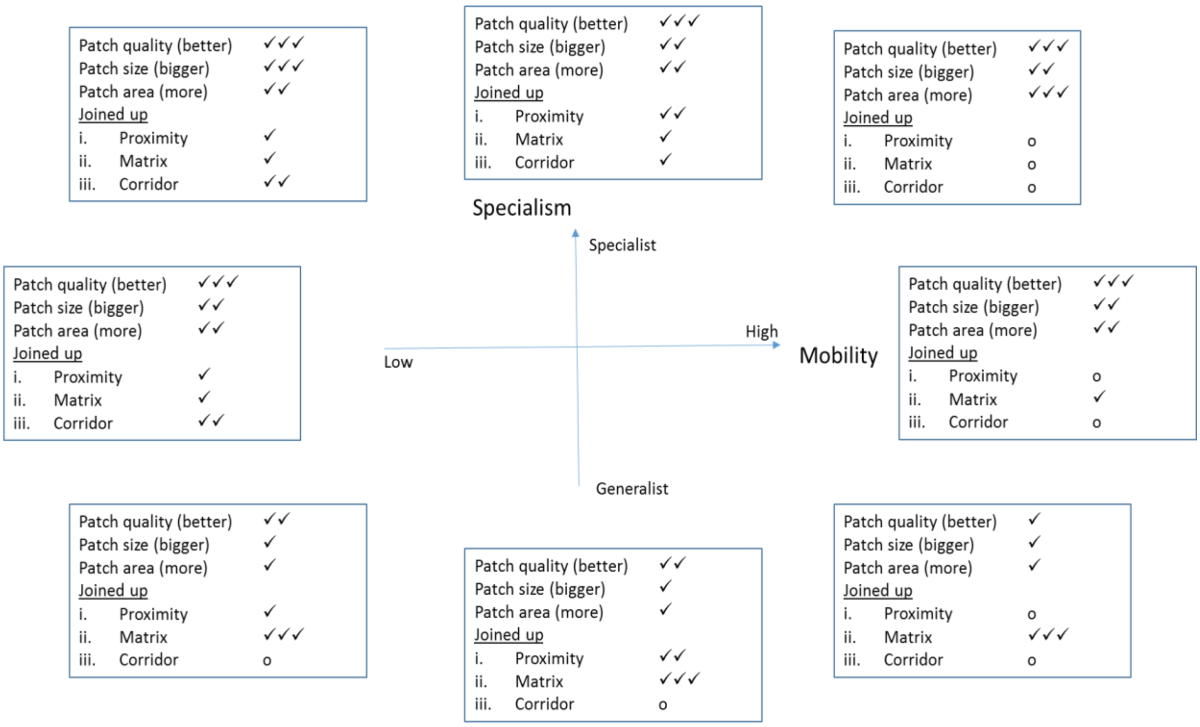
Better site quality > Bigger sites > More sites > Stepping stones & more permeable matrix > Corridors

While the order represented in this hierarchy is generally sound, the order can vary according to the species and landscape being considered (e.g. the relative cover of semi-natural habitats). For example, if one compares species along two axes that represent degree of specialism and degree of mobility, one can see that generalist species are likely to rely more on the matrix between high quality habitat sites, than the site themselves; and that less mobile species are likely to rely on the quality of the connectivity between habitat patches than more mobile species (see Box 2.4).

[15] http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/europe-north-america/ (Accessed 1/7/2019)

Box 2.4 Prioritising different elements of Nature Networks

Here we review the value of different network elements for species along two gradients (degree of specialism and mobility), the number of ticks indicate relative importance, and 'o' suggests relative unimportance. As every species is different, the importance of different aspects of a nature network will vary for individual species. For example, a species that has really poor mobility will be more affected by the joined-up nature of the landscape compared to a species that has moderate mobility. Equally, a species that can survive in multiple habitats will be less affected by the quality of a single habitat compare to a species that relies on that habitat. An understanding of how mobile and specialised is a species, helps identify which elements of a nature network to prioritise.



To accommodate species of the wider countryside, such as those that provide important ecosystem services such as pollination, or to support farmland birds, intervention should focus on the matrix. Conversely for more specialist species, which frequently include species of priority conservation interest, conservation interventions should focus on the patches of habitat.

In Appendix 2, we have reviewed the scientific literature to identify a number of rules of thumb to help practitioners design their nature networks. The aim is to help prioritise the different aspects identified by Lawton *et al*. (2010) and to provide some definition to the questions of how to make sites better, how big should they be, how and where more sites should be placed, and the best ways to improve connectivity. These have been summarised into one table (Table 2.4) although it should be noted that the application of these 'rules' will depend on the location, species and ecosystems of interest – the figures quoted are guidelines only, based on currently available evidence and should be used with due regard to local circumstances.

Table 2.4 Rules of thumb for the design of nature networks, building on the principles in Lawton *et al.* (2010)[16]

Better site quality >	Bigger sites >	More sites >	Stepping stones & permeable matrix >	Corridors
• Encourage natural processes • Encourage habitat mosaics • Create more niches for more species – use 'ecosystem engineers' and welcome ecological disturbance. • Increase messiness (variation of physical structure within sites). • Restore missing biodiversity by increasing niches or by reintroduction • Maintain rare species • Encourage climate colonists • Reduce edge effects by buffering sites and encouraging graded ecotones to 'soften the edge' • Buffer sites with at least a 50-100 m buffer strip, possibly up to 500 m wide • Maintain ecological continuity of management to protect soils	• Big enough to encourage natural processes – include sufficient area to ensure functioning ecosystems • Provide space for ecosystem dynamism, supporting mosaics and to encourage succession • Reduce edge effects by decreasing the edge:area ratio • Join habitat fragments; choose the ones that will create the biggest site • Restore degraded habitat surrounding the site. • Enlarge sites to >40 ha (or >100 ha for wide-ranging species)	• Add larger sites in preference to many smaller sites • Target areas of unprotected irreplaceable habitat or with a long ecological continuity of un-intensive land management • Target areas with complex or additional topography & geomorphology and with a potential to be climate change refugia • Target areas of important habitat potential in the surrounding area. • Target degraded areas with potential for high ecosystem service delivery. • Ensure connectivity is good for new sites.	• For poorly dispersing species, sites should be < 1 km from each other and < 200 m apart for highly specialised species within a habitat • Expand sites towards existing habitat to reduce space between patches. • Increase the cover of semi-natural habitat in landscape to at least 20% • Reduce the intensity and increase the diversity of landuse in the surrounding countryside • Stepping stones should provide appropriate resources to avoid becoming ecological traps	• Natural corridors are better than human designed corridors • Use linear landscape features • Ensure corridor habitat matches that in core sites • Minimum width of corridors = 100 m, preferably wider

[16] Please note that the figures quoted are guidelines only, based on currently available evidence and should be used with due regard to local circumstances. In this table, 'Site' does not necessarily mean a designated site, but an area of contiguous wildlife habitat.

When applying these rules of thumb to the design of nature networks, it is also important to take account of the following:

- **Large Nature Areas**, where priority is given to the conservation of biodiversity, are central to the development of a sustainable nature networks because they help improve the resilience of populations, buffer habitats and species from external pressures and because they are important sources of dispersing individuals for the rest of the network. In general, the bigger and the more naturally functioning, the better. They should aim to cover at least 5,000 to 12,000 ha.

- The **intervening 'matrix' of habitats between core sites is also important**, both for the species that use it as their primary habitat, but also for improving connectivity between core sites.

- We need to consider opportunities for **habitat mosaics**, at small and large spatial scales, to provide a wide range of resources and niches for species.

- The many individual species that make up ecosystems have different requirements and are influenced differently by external factors and pressures. It is therefore necessary **to have clarity about the species the nature network is intended to support** so that their complete life-cycles and inter-generational needs can be taken into account when designing the network. Nature networks need to be designed to take into account species' daily, seasonal and annual resource requirements, and the underlying geology and landforms.

- **Whenever possible, work with natural processes and give them enough space to operate**. This requires consideration of hydrology, nutrients, soil and sediment processes, factors that control vegetation growth and species composition. Thus, we need to build spatial understanding of the ecological processes for core sites, especially those stretching beyond the traditional boundaries.

- To make core willdife sites 'Better' is to make them '**Big Enough, Messy, Complex and Dynamic'**.
    - 'Big enough': Core sites need to be big enough to be able to function well ecologically, with natural hydrological processes and rich food webs, so that they are more resilient.
    - 'Messy': sites that are physically messy, with mosaics of habitat, and a diverse structure that provides more niches for species and refuges in times of environmental stress (e.g. drought).
    - 'Complex': sites with a complex and rich biodiversity and full food webs, as these will be more resilient to external shocks and environmental stresses.
    - 'Dynamic': well-functioning ecological networks are dynamic and may involve shifting mosaics of habitat types at a range of spatial scales.

- **Edge effects** can decrease habitat quality within a habitat patch, so more compact habitat patches are usually desirable. However, these negative impacts on species can be mitigated by the encouragement of graded edges, such that one habitat gradually merges with another. Such graded edges can be beneficial for some species.

- **Climate change refugia** should form key parts of ecological networks as they are likely to improve resilience for species within landscapes. These are areas that are less susceptible to climate change, supporting the persistence of species within an area affected by climate change, for example north-facing slopes which are cooler (Suggitt *et al*. 2014).

- **Rare, long-distance dispersal events** are likely to be important for many species; receptor site quality and quantity is therefore very important.

- Within an isolated location, at least 50 individuals of a plant or animal species are required **to avoid problems with inbreeding**; and for connected populations, at least 500 are required to maintain long-term genetic viability. **Overall, conservationists should seek to achieve a population size for a species of at least between 500 and 5000 individuals**, depending on body size, to sustain a species faced with environmental pressures and random events.

Taking all of these together, the general directions of travel for nature network establishment are summarised in Fig. 2.4, below.

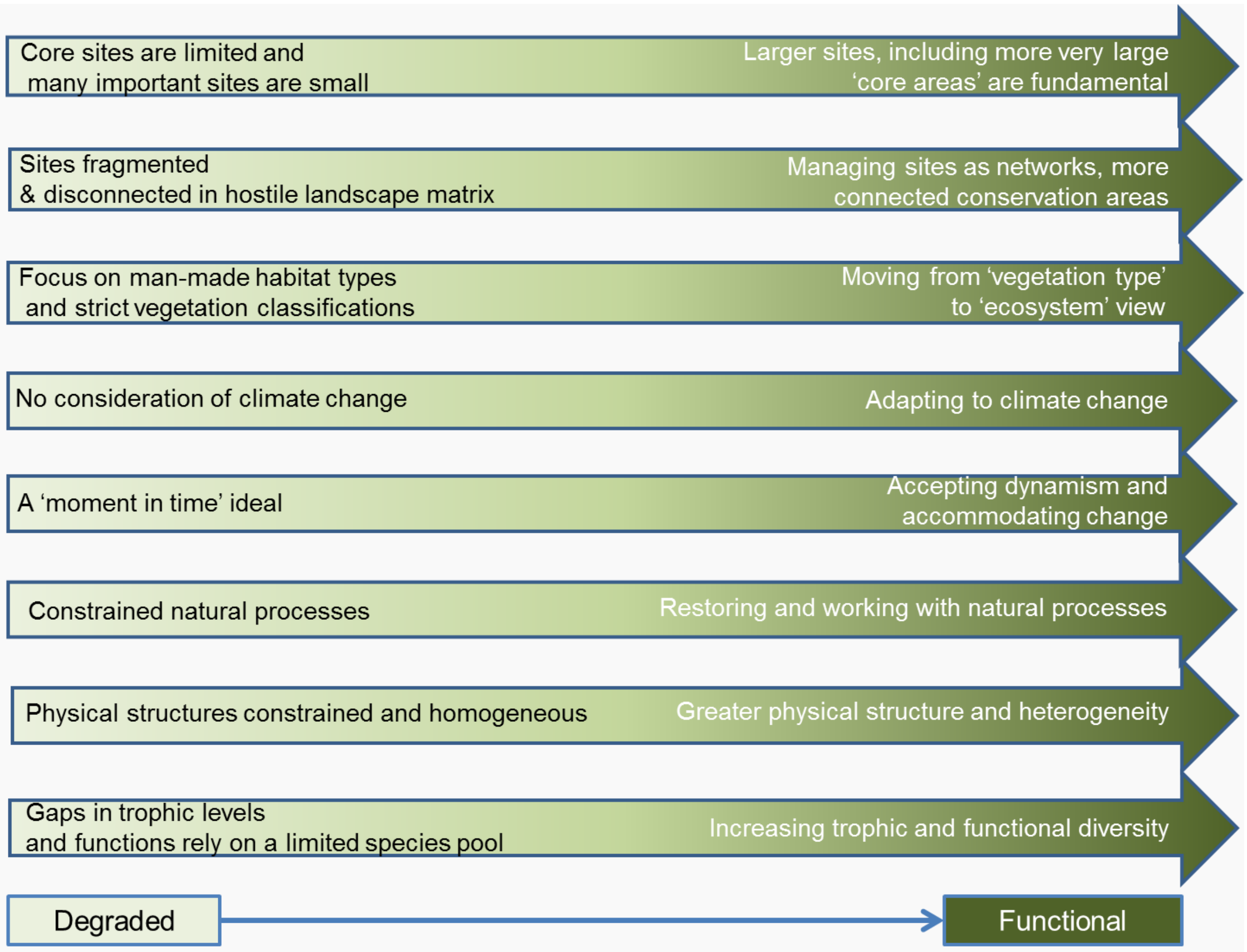


Figure 2.4 The direction of travel for ecological components of a nature network

3 Implementing a plan for a nature network

Summary

- When implementing the plans for a nature network there are various key practical aspects that need to be considered: working within the planning system, working with landowners and farmers and working with the natural processes that operate within a landscape.

- The planning system is a major statutory instrument that can be used to help implement appropriate land use within and adjacent to a nature network. The National Planning Policy Framework provides numerous requirements on local authorities that support nature network development, including the use of green infrastructure, and the concept of Net Gain is also a potentially powerful tool.

- Agri-environment schemes provide the opportunity to work with farmers and landowners to support nature network development and ‘farm clusters’ are a particularly useful mechanism to improve landscape-scale collaboration.

- At a practical level, working with natural processes within a landscape requires thinking about hydrology, nutrients, soil and sediment processes, vegetation controls and species composition. Decision making operates at a number of spatial scales, from landscape to species, but being aware of the needs of finer-levels of organisation at each level. We provide a list of useful detailed habitat management manuals that can inform action at the site level.

- Finally we provide a flow chart to suggest how a nature network can be developed in practice, with reference to the evidence provided in this handbook.

3.1 Introduction

Having made a range of decisions about how a nature network might look – first having developed a vision with stakeholders using participatory approaches and based on the 10 Principles outlined in Chapter 1; then having outlined how it can meet the needs of the area, by taking into account landscape and geodiversity, the ecosystem services the network should provide, and how it can create a quality network that will result in abundant wildlife (Chapter 2); it is now necessary to think about putting some of these suggestions into practice.

There are a wide range of guides on how to manage specific habitats and also range of tools that can be used to help to work out where the optimal places are to place different elements in the landscape. The latter are described in chapter 4, but in this chapter we will identify some useful ways of working that can be considered during the implementation of the plan for a nature network.

We will discuss:

- working with the planning system;
- working with farmers;
- working with natural processes; and
- the range of habitat creation and restoration guides that are available.

Finally, we provide an overall flow chart to show how the process of developing a nature network might proceed in practice, from the initial stages of deciding that a nature network could be valuable in a location, through the planning stages and to implementation.

3.2 Working with the planning system

When implementing a plan for a nature network, the planning system is a major statutory instrument that can be used to help implement appropriate land use within and adjacent to a network. The planning system is set up to regulate land use in an efficient and ethical way, with the presumption in favour of sustainable development. There are some broad categories of land use types, such as urban, peri-urban, rural and linear infrastructure (road, rail, canals etc.), which can all add components to a nature network but it is important to note that they will have differing delivery partners, tools, and practices.

Section 40 of the Natural Environment and Rural Communities Act 2006[17] places a duty on all public authorities in England and Wales to have regard, in the exercise of their functions, to the purpose of conserving biodiversity. Thus the revised National Planning Policy Framework (NPPF; Ministry of Housing, Communities and Local Government 2018) for England provides a statutory basis for local planning authorities (LPA) to '*take a strategic approach to maintaining and enhancing networks of habitats and green infrastructure'*, '*enhancement of the natural, … environment, including landscapes and green infrastructure*' and '*by establishing coherent ecological networks*'. In doing so, LPA can plan for the needs of the community while safeguarding and enhancing natural resources. Thus, the NPPF provides a large number of 'hooks' on which to hang the development of a nature network - see Appendix A3.1 for useful details.

Paragraph 175 of the NPPF is based on the commonly used '**mitigation hierarchy**' that describes the actions that should be undertaken to avoid damage to the natural environment (see Bull *et al*. 2018). Ideally a detrimental development should be **avoided.** If this is impossible, then any damage should be **minimised**. Such unavoidable damage should be **remediated** (e.g. through the replanting of native vegetation), or if this is not possible, then consider **offsetting** the loss, by creating or restoring replacement habitat elsewhere, thereby ensuring 'No Net Loss' of biodiversity. The updated biodiversity offsetting mechanism, *Biodiversity Metric 2.0* provides a way of measuring and accounting for biodiversity losses and gains resulting from development or land management change. (Crosher *et. al*. 2019)

More recently, the concept of '**Biodiversity Net Gain**' (Rainey *et al.* 2015) has gained currency: defined as development that leaves biodiversity in a better state than before, by more than making up for any losses to natural habitat as a result of development. This has been included as an important component of the Defra 25 Year Environmental Plan I (Defra 2018a). The major characteristic of Net Gain is for developers to work with local and county councils, wildlife groups, land owners and other stakeholders in order to support the priorities for nature conservation. This provides a new way to support a rehabilitated natural environment, by restoring important missing areas and enhancing exiting areas of a nature network. These opportunities are now being demonstrated in many places across the country. While it is important for Net Gain to more than make up for the losses of biodiversity due to development, it is also important to consider the impacts on society, so that communities don't lose access to important green space near where they live: this is encapsulated in the concept of 'No Net Loss for People as well as Biodiversity' (Bull *et al.* 2018).

[17] http://www.legislation.gov.uk/ukpga/2006/16/section/40 (Accessed 4/2/19)

3.2.1 Green infrastructure

The NPPF includes frequent references to 'Green Infrastructure' (GI) which it defines as 'A network of multi-functional green space, urban and rural, which is capable of delivering a wide range of environmental and quality of life benefits for local communities.' This is a useful concept with respect to the development of nature networks, although with more emphasis on people. Thus, GI is about working with landscapes and nature to provide services and benefits for people and the economy. Some people also use the term 'Blue Infrastructure' to refer to the freshwater elements of GI or those that occur in coastal and marine systems (da Silva & Wheeler 2017). GI is a critical infrastructure just like transport and so also needs to be strategically planned.

Well designed and managed GI can provide ecosystem services thereby supporting sustainable economic growth and social objectives. Sympathetically designed GI can benefit wildlife, both common and rare, and be part of an ecological network. The approach involves understanding what services and benefits an area needs and then considering what types of GI can best deliver these and how they can be connected to other new or existing GI (or other service infrastructure) to optimise the benefits.

While GI has a very broad definition, it is often used in the context of urban areas where it can contribute to biodiversity, landscape quality and the health and well-being of people. It can help provide links between urban and rural areas, helping to reduce barriers created by urban areas, as well as being important for the urban environment. The provision of large greenspaces and corridors within urban areas are beneficial for wildlife (Beninde *et al*. 2015). GI also improves health and well-being for people within urban areas (Tzoulas *et al.* 2007), particularly mental health (Fuller *et al*. 2007; Flouri *et al*. 2018).

Useful guides to the creation of GI in urban and other areas include:

- *Demystifying Green Infrastructure* (UK Green Building Council 2015), which provides numerous case studies and references to other publications.
- *Green Infrastructure – An Integrated Approach to Land Use* (Landscape Institute 2013), which describes underlying design principles and numerous case studies.
- A range of Natural England guides, for example a GI Guidance document (Natural England 2009), a review of the tools that can be used to estimate the value of GI to society (Ozdemiroglu *et al*. 2015), and a number of case studies (e.g. Victoria, London (Natural England 2013a) and Tees Heritage Park, Stockton-upon-Tees (Natural England 2013b).

3.3 Working with farmers

Approximately two-thirds of England is agricultural land (arable, horticultural or improved grassland) and thus heavily influenced by farming practices (Natural England 2008). Farmers and landowners are therefore key stakeholders in the development of nature networks. Not only because they are often the owners of important sites that are designated as SSSI, but also because they influence the management of much of the land surrounding core sites within a network. Their activities may not only affect the permeability of the surrounding landscape, but can impinge directly or indirectly on the special sites themselves (e.g. pesticide spray drift, water abstraction, diffuse pollution). The use of incentives from agri-environment funding (such as Countryside Stewardship) can be critical for improving high biodiversity sites, as well as for improving the permeability of the landscape (i.e. to facilitate movements by nature) and connectivity (e.g. by maintaining small patches of land as stepping stones, or improving the quality and connectivity of hedgerows across the landscape). Much of the guidance provided to farmers to satisfy the options allowed under such schemes is aimed at improving the quality of the land for nature, and provides useful reference material, even though the particular scheme may no longer be running (e.g. Natural England 2010).

At a landscape scale, one of the most potentially useful approaches is through the support of '**farm clusters**' (Dent 2018). These were piloted by the Game & Wildlife Conservation Trust and have been adopted increasingly widely with some success. Essentially this is a land-owner led approach, whereby groups of farmers, foresters and other land managers come together to implement a shared vision for their collective land, see https://www.farmerclusters.com[18] for a description of how to set one up, how they work, examples of case studies and a range of guides covering aspects such as monitoring, carbon accounting, and some aspect of land management. A key aspect is that they need a facilitator to administer the cluster, seek funding and organise activities and training. Such farm clusters help farmers to work at a landscape scale to improve the links between initiatives on adjoining farms – thus they can actively coordinate to make habitat patches bigger and better, where they cross farm boundaries, and improve connectivity by making sure there is continuity between land holdings. A good example can be found in the Marlborough Downs Nature Enhancement Partnership, which has engaged 56 farmers and land managers of 28 agricultural holdings covering c. 9000 ha. Over the first four years of their partnership they have created a pond network, a tree sparrow corridor, improved the chalk grassland network, created habitat for pollinators and improved access and learning opportunities for local communities (Batten 2017).

3.4 Working with natural processes.

One of the key parts of the creation of nature networks is to develop a less interventionist approach to ecosystem management that embraces dynamism and works with natural processes (Principles 4, 5 & 6 – sections 1.2.1; A2.3.1). The inherent characteristics of the landscape (geology, topography, soil types and the natural hydrological, hydro-chemical and geomorphological processes they generate) provide a reference template for habitat provision. We should use this as a starting point in planning habitat networks and in understanding how to restore natural ecosystem function and associated habitat mosaics.

Although described briefly in sections 2.2.3 and A2.3.1, what does working with natural ecosystem functions and naturally functioning habitat mosaics really mean? We have to think broadly to appreciate these terms, considering the range of natural processes that shape and sustain habitats (Box 3.4). The outcomes of these natural processes are dynamic habitat mosaics at multiple spatial and temporal scales, with extensive transitional zones (wet to dry, open to closed vegetation, bare soil and sediment) capable of catering for the full native species complement of a locality. These mosaics can include our more 'cultural' semi-natural habitats (e.g. different types of meadow, heathland etc.), in a spatial pattern that fits into a more naturally functioning landscape. A full review of working with natural process and mosaics is provided in Mainstone *et al.* (2018).

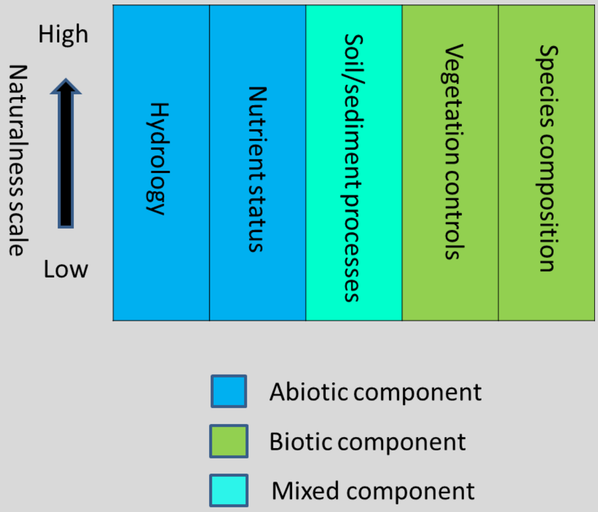
All landscapes have a natural habitat template defined by geology, soils, topography and climate, a set of human modifications to that template built up over long periods of time, and a set of constraints imposed by how we use and live in landscapes today. In management terms, natural abiotic processes provide a set of habitat and species assemblage opportunities, from which management choices can be made through biological controls on the vegetation – the more these vegetation controls mimic the action of natural herbivores within a natural foodweb (predators, disease, resource limitation), the better the overall outcomes for biodiversity are likely to be. In surveying our options and choices it is really important to understand that, while there are clearly wrong options, poor options and suboptimal options, there is seldom a single right or correct option. Furthermore, socio-

[18] Accessed 4/2/19.

economic constraints to restoring natural function can set pragmatic limits on our biodiversity aspirations.

England is a densely populated country with strong historical and contemporary cultural influences on the landscape. There are considerable constraints on how far natural ecosystem function can be restored, and there are potential adverse consequences for our remaining biodiversity, and other environmental and socio-economic objectives, if pursued in the wrong way or in inappropriate areas. From a biodiversity perspective, some of our native species (e.g. farmland birds in the past) have benefited from human modifications to landscapes, creating more optimal habitat for them at the same time as eliminating the habitat required by other species. In restoring natural ecosystem function, species associated with strongly man-modified habitats are likely to do less well, while others flourish. Local decision-making needs to target the best places, maximise opportunities and minimise disbenefits. Examples of how to apply these concepts in a range of ecosystems are provided in Appendix A3.2.

Box 3.4 Key elements of natural function



This diagram shows five key elements of natural function. If all elements are in a highly natural state then the system can be thought of as pristine. But in our cultural landscapes we have to aim for levels of natural function that are practically achievable and take account of other societal priorities.

***Hydrology* –** The pathways that water take through catchments are a fundamental determinant of habitat and species patterns. This holds true for all habitats, from open water to habitats such as dry heath, and their associated species. These pathways not only determine wetness patterns in the landscape but also the natural hydrochemistry of water (alkalinity, trophic status etc.), which has a fundamental bearing on habitat and species patterns. Disruptions to natural hydrology include drainage, abstraction, water diversion, flood defence and pathway blocking by urban and industrial development and associated infrastructure.

***Nutrient status* –** The availability of major plant nutrients shapes natural ecosystems. In natural ecosystems nutrients are generally scarce relative to their availability in developed landscapes. Increased availability through regular cultivation and fertilisation of soils and the disposal of sewage and industrial waste has severe detrimental effects on aquatic, wetland and terrestrial habitats, including our more cultural semi-natural habitats such as grasslands and heathlands. The many species of natural habitats that have evolved to capture scarce nutrients in an efficient way are out-competed by a smaller number of species that have evolved to exploit natural spikes in nutrient availability (e.g. animal dung). This changes and simplifies foodwebs and reduces natural species diversity. In aquatic systems, excessive nutrient inputs can lead to eutrophication with associated algal blooms and loss of species through oxygen depletion when algae die and decay.

Soil/sediment processes - This is a more heterogeneous group of processes covering both soil health (organic matter content, soil microflora) and patterns of sediment erosion and deposition in the landscape. Terrestrial habitats rely on healthy soils, whilst aquatic habitats are fundamentally shaped by the movement of sediments (creating diverse habitat mosaics in river, lake and coastal ecosystems). Natural function in this context relates to the freedom of soil and sedimentary processes to build and shape habitat mosaics with characteristic levels of dynamism, e.g. the formation of peat in water-logged conditions (a slow, stable process), the development of humic woodland soils, the lateral erosion of river channels and creation of exposed shingle banks (a highly dynamic process in many river types), and the continuous formation of sand dunes (strong dynamism, requiring a supply of sediment for new dunes to maintain vegetative succession).

Vegetation controls – This largely relates to the nature and intensity of biological controls on vegetation succession, over and above the abiotic controls on vegetation development outlined above. In natural ecosystems 'Keystone Species' can play a dominant role in exerting vegetation controls: for example herbivores, controlled at levels determined by resource availability or by predators. In modified landscapes vegetation control is determined by agricultural grazing, cutting (e.g. in woodland management) and burning (e.g. on upland moorland). The high intensity of some types of human control (e.g. intensive forestry) is highly detrimental to the expression of naturally functioning habitat mosaics. Alternatively, human controls can be designed to mimic natural controls in ways that contribute to habitat mosaics, e.g. the management of hedges to mimic scrub in the landscape. Low natural function in vegetation controls may result from intensive human management (livestock grazing or cutting), or excessive grazing and browsing by native species due to a lack of population control by native predators (which have been removed by hunting), or damaging levels of grazing or disturbance by non-native species.

Species composition – In natural ecosystems species composition is shaped by the habitat mosaics formed by the four types of natural process outlined above. They are therefore, in large part, a reflection of the naturalness of those processes. However, in addition to impacts on these natural processes, species composition can be affected by direct biological impacts. The impact of non-native species on native assemblages can be as great as any other, and can sometimes extend to effects on physical habitat provision (e.g. river bank destabilisation by signal crayfish and Chinese mitten crab). Also included under this element of natural function are direct manipulations of native assemblages, including human activities such as the selective removal of trees species from native woodland, and the removal of unwanted native fish species and the introduction of quarry fish species in freshwaters.

3.4.1 Decision-making framework

When considering natural processes, it is useful to consider the framework outlined in Fig. 3.4.1. Conservation decisions are made at a number of different spatial scales from landscape to site or patch level to field level. At each scale awareness of wider requirements and larger issues builds better long term results. For instance, when managing the habitat at a heathland site one must be aware how the management will impact species of interest – will grazing at a certain level of intensity have unintended consequences for key heathland species, for example? Then at a wider scale, when considering the restoration of various key ecological processes such as the hydrology of the area what will be the impact on certain drier habitats? Finally, when looking at the wider landscape, spatial planning to help create the overall nature network needs to be aware of how the various natural processes, such as hydrology will work within parts of that landscape.

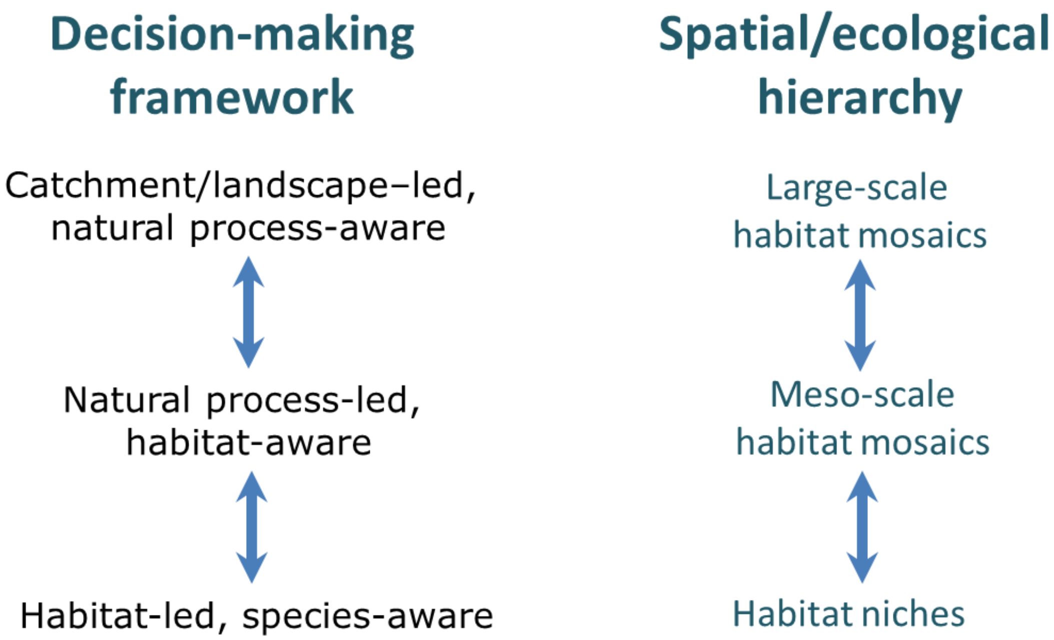


Figure 3.4.1 Building better ecological networks through more naturally functioning habitat mosaics

This is about approaching decision-making with the right mind-set, rather than trying to prescribe a specific outcome. Greater understanding of where habitats and species are naturally located in landscapes, a willingness to challenge perceived constraints and take a long-term view to overcome them, and adequate consideration of how to transition vulnerable species into restored naturally functioning habitat mosaics, will help generate the most integrated outcomes for biodiversity, natural capital and people (see Appendices A3.3 for a list of practical ecological considerations that build on the Principles outlined in chapter 1 and the ecological evidence in chapter 2).

Given the fundamental influence of water in the landscape, and the large-scale land drainage and flood defence works that have occurred in England, **consideration of water (freshwater and coastal) is often central to identifying the best opportunities for restoring naturally functioning habitat mosaics**. Restoration of natural hydrological pathways in the landscape, not only helps to generate naturally functioning habitat mosaics, but also to deliver a range of socio-economic benefits associated with water (diffuse pollution control, catchment water storage etc.), by improving natural capital and ecosystem services (water quality and supply, flood risk management). Identifying and generating vegetation management regimes that mimic natural controls, to provide an appropriate mix of open, scrubbed and wooded habitats, disturbed and undisturbed soils, is a subsequent consideration but equally fundamental. In most cases, this vegetation balance will involve increased scrub and woodland cover, which will not only restore more natural and biodiverse habitat mosaics but also improve a range of water-related ecosystem services (Nisbet *et al*. 2011). Restoration of natural nutrient supply and status, and the control of non-native species, are further layers of decision-making that ensure we get the desired response from native plant communities, and through this, native fauna.

3.4.2 What should we do with small sites?

Much of the guidance and evidence provided above and in chapter 2 suggests that conservationists should concentrate on making sites bigger and working towards sites that are at least 40-100 ha in extent, big enough to allow natural processes to operate. The evidence suggests that small sites will be less resilient, more prone to edge effects and will require more management to keep them in good condition and subject to progressive species loss due to 'extinction debt'. Furthermore, small sites are less cost-effective (in terms of cost per unit area conserved) than larger sites (Armsworth *et al.* 2011). So, does that mean we should abandon them or not designate such sites if an opportunity or need arises?

There are a number of good reasons why small sites should not be dismissed. Under suitable management and without the harmful effects of severe weather or detrimental anthropogenic events, populations can persist on small sites for reasonable periods (Lawton *et al.* 2010) although there is relatively little evidence available on this issue. Small sites can be valuable in the short to medium term, as refuges for rare species or habitats especially if the surrounding countryside is relatively benign. In addition they may be small 'oases' of un-improved soils within a landscape and thus valuable as centres for future enlargement to improve their resilience and secure the biodiversity interest. Small sites may be valuable as stepping stones – facilitating the dispersal of species between larger core sites. Finally, small sites might have value as part of a suite of sites that support a metapopulation – for example calcareous grassland butterflies can maintain themselves on such suites of such sites through recolonising sites where local populations go extinct (Hanski 1998; Skirvin et al. 2013).

3.5 Useful guides to practical habitat and geodiversity management, restoration and creation

There are a wide range of practical guides to habitat restoration that have been published over the years by a range of governmental and non-governmental conservation organisations. These provide detailed descriptions of how to undertake specific habitat management techniques and bring together the collected experience of many conservationists. We cannot provide an exhaustive list of such guides, but a summary of a range of useful guides is provided in Appendix A3.4.

3.5.1 Favourable Conservation Status (FCS)

This is a useful tool with which to consider the needs of individual species and their habitats – these are a set of definitions for priority habitats and selected species that outline what is required to ensure that they thrive in the long term. FCS has its foundation in 1979 Bonn Convention on Migratory Species and aims to show how an area (usually individual countries) can make its necessary contribution to achieving FCS throughout the whole natural range of the habitat or species.

FCS definitions and strategies can usefully inform spatial targeting at the landscape scale for conservation management purposes, with the aim of ensuring that landscapes make an appropriate contribution to achievement of FCS in England. It is also helpful to inform wildlife licensing decisions and regulatory decision making, including identifying compensatory habitat requirements. Further information can be found at in the *UK Statutory Nature Conservation Bodies Common Statement on Favourable Conservation Status*[19].

3.5.2 Conserving geodiversity

At a practical level geoconservation includes maintaining and enhancing both physical and visual access to the characteristic geodiversity of a Nature Network. This includes the management of

[19] http://archive.jncc.gov.uk/pdf/FCS18_InterAgencyStatement.pdf (accessed 20/1/20)

natural and man-made exposures, the physical characteristics (geomorphology) of the landscape, and the natural processes which continue to shape the landscape and maintain a functioning natural environment.

For natural (such as inland outcrops and coastal cliffs) and man-made (such as quarries and road cuttings) rock exposures management typically includes removal and control of vegetation, the removal of scree and debris build-up, and re-excavation where exposures have become concealed. For static geomorphology (such as glacial moraines or limestone pavement), managing vegetation encroachment and avoiding loss of geomorphological features through changing land use are important. For active geomorphology (such as river and coastal systems) maintenance and re-establishment of natural processes is critical.

Geological conservation: a guide to good practice (Prosser, Murphy & Larwood 2006) provides a comprehensive guide to geoconservation and includes a number of illustrative case studies (see Box 3.5.1 for more recent examples).

Box 3.5.1 Examples of how geoconservation and biodiversity conservation can support each other

Kings Dyke Nature Reserve, near Peterborough – integrating biodiversity and geodiversity management. A restored area of an active Jurassic Oxford Clay brick pit Kings Dyke provides a mix of ponds and associated habitats. A recent bioblitz recorded over 1100 species, and the site includes important stonewort and Great Crested Newt *Triturus cristatus* populations. An area of the Kings Dyke Nature Reserve encompasses permanent sections through the Oxford Clay and has a fossil collecting area (refreshed with clay from the active pit) that yields a diverse fossil fauna including marine reptiles.

Moor House National Nature Reserve, North Pennines – ecological relationship between geodiversity and biodiversity. Moor House NNR is characterised by Carboniferous sandstones and limestones, overlain by glacial tills and peat. Intrusion by the Whin Sill dolerite into the limestone produced the distinctive ‘sugar limestone’, a coarsely crystalline marble which weathers slowly to a thin, drought prone soil, with a grain size similar to granulated sugar. The sugar limestone and its associated seepages supports one of the richest groups of rare species in Britain including spring gentian *Gentiana verna* and the endemic Teesdale sandwort *Minuartia stricta*.

Understanding geodiversity to manage biodiversity. The rare shore dock (*Rumex rupestris*) is generally restricted to south-west England linked to coastal flush or seepages. Understanding this ecological and geological relationship has enabled field survey to be designed based on geological mapping. This increased the known shore dock population by 30%. This method can be used widely to identify suitable habitats for survey and habitat recreation, an approach that can include invertebrate species such as the cliff tiger beetle that requires damp environment with running water and shading, again associated with coastal flushes.

3.5.3 Adaptation to climate change

This is an over-arching issue that needs to be considered at an early stage nature network development. Furthermore, nature networks are also a key part of reducing the vulnerability of wildlife and their habitats to the impacts of climate change (see Box 3.5.2). The main source of information on practical climate change adaptation for conservationists in the UK can be found in the Natural England & RSPB (2014, 2020) *Climate Change Adaptation Manual*[20].

Box 3.5.2 Climate Change Adaptation through Nature Networks

The climate is changing: temperatures have increased by nearly 1 °C in the UK in recent decades; summer rainfall has decreased (although this has been reversed in recent years) while winter rainfall has increased; more rain is falling in heavy storm events, increasing the risk of flooding, and sea levels are rising by approximately 3mm per year. The impacts of these changes on the natural environment can already be seen (Morecroft and Speakman, 2015). Models of future climate show that these trends will continue and potentially increase with the potential for more summer drought and winter and summer flooding.

The development of nature networks is an important form of nature-based solution to help nature – and ourselves – adapt to a changing climate. But it is also essential to take climate change into account in developing networks:

- Building resilience through creating better, bigger, more and joined up areas for wildlife and through restoring natural processes is an essential starting point for reducing the risks from climate change. Targeted habitat creation and restoration can also be used to reduce specific climate change threats, for example through the reduction of the susceptibility of wildlife areas to drought.
- Enhancing a more natural hydrological regime in a landscape promotes resilience to both droughts and floods, by increasing water storage as a buffer against drought and allowing water courses and habitats to adapt naturally to fluctuating water levels.
- Maintaining coastal habitats despite rising sea levels depends on allowing the shoreline to shift and new habitat to form inland to compensate for areas which are lost to the sea. Ensuring that coastal habitats have the space to migrate inland naturally or through managed realignment is vital for the resilience of coastal networks.
- Locations with topographic heterogeneity and structural complexity provide a range of microclimates so species will be able to persist and adapt to changes, both through the variation in seasonal events and longer term changes to the microclimate.
- Some areas support the persistence of species that would otherwise be lost as a result of climate change. These are often areas which are locally cool as a result of their altitude, aspect or location close to the coast. Recognising and protecting these climate ‘refugia’ areas within nature networks increases the chances of maintaining species in a landscape.
- Larger and less fragmented wildlife sites can improve the resilience of populations to fluctuating weather conditions and extreme events. Larger populations increase the chances that at least some individuals survive adverse conditions.
- Increasing connectivity will allow some species to spread across the landscape and colonise new areas that may be more suitable for them in a changing climate. This is most likely to benefit species of intermediate dispersal capacity. However, it should be noted that this may, in some cases, increase risks from invasive non-native species, pests and diseases.
- Some change is inevitable even with resilient ecosystems and nature networks and it is important to ensure that conservation planning takes account of inevitable change and manages for best outcomes in changed and potentially unpredictable circumstances. This includes adjusting conservation objectives for sites to reflect changing environmental suitability for different species.

[20] http://publications.naturalengland.org.uk/publication/5629923804839936?category=10003 (Accessed 1/2/19)

3.5.4 Conservation Evidence

One other valuable source of information can be found in www.conservationevidence.com[21] which aims to summarise scientific publications of conservation interventions and publishes an associated on-line open-access journal. *Conservation Evidence* also publishes synopses of evidence for particular topics, listing all the possible actions that can be taken to conserve a given species group or habitat or to tackle a particular conservation issue. For each action, a summary is provided that brings together the available scientific evidence so that it is quick and easy to read. Published synopses that are particularly relevant to the development of nature networks are:

- Peatland Conservation
- Shrubland and heathland conservation
- Forest conservation
- Farmland conservation
- Soil fertility
- Amphibian conservation
- Bat conservation
- Bird conservation
- Bee conservation
- Control of freshwater invasive species

3.6 An overview of the process of designing a nature network

To bring together and summarise the various stages in Nature Network design, we have put together a flow chart to show the various logical stages that might be followed by a partnership wishing to develop a nature network in their area (Fig. 3.6).

[21] Accessed 20/1/2020

Figure 3.6 Stages to be undertaken in Nature Network design and delivery

Step 1: Evidence gathering to develop an initial vision for the nature network

1. Understand the place and assess what aspects of nature are special about an area or have been degraded or become threatened
    a. Landscape character & beauty
    b. Geology & soils
    c. Natural processes (e.g. hydrological, geomorphological)
    d. Biodiversity
        i. Identify existing and potential core sites for biodiversity
        ii. Identify opportunities for expansion and joining up existing areas and for improving their natural functioning
        iii. Review matrix (land between core sites)
            1. Identify important species and habitats
            2. Identify opportunities to improve connectivity
    e. Ecosystem services
    f. Historical environment
    g. Socio-cultural context (e.g. traditions, affluence, life-styles etc.)
2. Assess what aspects of nature could be restored or created, taking into account current and potential national importance
3. What opportunities are there for new or enhanced ecosystem service provision
4. Think in a network way rather than about individual sites

Step 2: Identify and involve stakeholders in refining the vision

1. Develop a stakeholder map based on land ownership and ecosystem service provision and usage
2. Hold a workshop to review the initial vision and to refine it
3. Use a variety of tools to present relevant data
4. Identify opportunities
    a. For ecosystem restoration and habitat creation
    b. For restoring natural processes
    c. For new and enhanced ecosystem service provision
5. Use participatory approaches to engage with the wider community to encourage support and to refine the vision further

Step 3: Prepare final vision

1. Agree ultimate goals for nature network
    a. Biodiversity goals
    b. Natural capital goals
    c. Ecosystem service goals
    d. Landscape character and cultural heritage
    e. Other societal goals, such as access to the countryside
2. Agree constraints and opportunities
    a. Ecological issues e.g. soil types, likely climate change impacts, natural processes
    b. Landscape issues e.g. cultural expectations
    c. Cultural issues e.g. population make-up
3. Agree areas of uncertainty including aspects requiring a search for compromise
4. Agree size of area over which the network will be designed
5. Identify links to wider networks
    a. Including how it contributes to national and regional needs
6. Develop a suite of targets against which progress can be assessed

Step 4: Develop a project team for the delivery of nature network vision

1. Develop an organisational and governance structure
2. Identify leads (teams) for each key aspect of the project
3. Teams to develop aims and objectives for their component of the project
4. Project teams work together to ensure an overall integrated plan
5. Implement plans
    a. Start immediately, but think long-term

Step 5: Building the Nature Network

1. Build resilience
    a. What are the pressures?
    b. Think about social resilience
2. Design the nature network using the suite of rules of thumb
    a. Make sites better
        i. Big enough, complex, messy, dynamic
        ii. Enhance natural processes
        iii. Develop buffers where possible
    b. Make sites bigger
    c. Create new sites
    d. Improve connectivity
    e. Improve quality of resources for wildlife in the wider countryside

Step 6: Implement the plans

1. Work with the planning system
    a. National Planning Policy Framework in England
    b. Net Gain
    c. Green Infrastructure
2. Working with farmers and landowners
    a. Use of agri-environment schemes where practicable
    b. Benefits of farm clusters
3. Detailed ecosystem management
    a. Tailored to improving and using natural processes, working towards rewilding where appropriate
    b. Tailored to specific habitats

Step 7: Undertake monitoring and surveillance to allow evaluation of nature network

1. Develop a programme to monitor progress that takes into account local and national objectives
2. Refine implementation plan as it progresses in the light of evaluation (adaptive management)
3. Undertake management interventions scientifically to grow the evidence base.

4 Useful map-based models and tools

Summary

- Conservation practitioners need access to a range of information and spatial tools to help design and implement nature networks
- We identify and describe seven mapping datasets, five spatial mapping decision-support tools and two conservation planning tools that are potentially useful for the planning of nature networks
- There are a range of common issues to consider when using these datasets and tools, including data quality, spatial scale, level of complexity and uncertainty – thus their use and outputs need to be considered carefully and in full awareness of underlying assumptions.

4.1 Introduction

Conservation practitioners need access to a range of information to help design and implement nature networks. The use of spatial data and tools, is essential to analyse different aspects of nature networks in their landscapes and to support decision making. However the range and complexity of these resources can be confusing. This section aims to help potential users by summarising a range of evidence-based tools, models and data that Natural England has found useful when planning nature networks. This includes a description of their evidence basis, what they can be used for, how they help to inform conservation decisions. Although we summarise each tool below, more detailed assessment is also available in Appendix 4. More general tools and assessment methods, for example, those that help us assess landscape character, are not covered here.

The input datasets for the tools we describe in this chapter are often specific to particular land uses, habitats or species. Other knowledge-building datasets and tools, covering such areas as landscape quality, recreation assets, demographics and the historical environment as examples, will need to be used alongside these to undertake a fully integrated analysis for a local area.

This section cannot give definitive answers on which tools to use or how to use available data, or provide an exhaustive list of available ecological network assessment tools and data. However, it does provide a summary of what we think are important, useful and relevant tools that can be used in any landscape. Understanding and collating the existing data for a place (Box 4.1) is an essential first step before deciding to use the models and maps detailed in this chapter.

4.1.1 Setting the 'Place based' context

Before identifying the tools and data to use, start by identifying the focus of the ecological network and the conservation objectives for your ecological network (as outlined in chapters 1 & 2). For example: do you have a particular species or habitat in mind? Which multiple benefits, or ecosystem services, are you focussing on? Is it needed here, perhaps by way of contributing to some national target? Early thinking on these aspects can be enhanced by gathering and viewing existing datasets, with the added benefit that these may be useful inputs into some of the spatial tools outlined below.

Setting the wider context can also help identify multifunctional benefits or opportunities to be gained from delivering ecological network enhancement. It may also highlight where proposed benefits for one asset may have negative impacts on another. This may in turn highlight where a more in-depth assessment and discussion of the way forward may be required. Box 4.1 lists some of the data and evidence that is useful for setting the context for a nature network in a place. This helps us to think about what we know about a place, its geology, soils, landscape character, topography, and a range of other environmental variables, essential for the spatial design of a network. It also assists with planning a network in the context of a multi-functional landscape, addressing constraints as well as opportunities to deliver multiple benefits.

Box 4.1: Useful evidence and data sets for understanding your place

Develop your understanding of your area before undertaking any further analysis detailed in this chapter. Many of these data sets may be used as input layers for further analysis and modelling.

- Ordnance Survey base maps
- Soil and geology maps e.g. from the British Geological Society or National Soil Resources Institute
- Topography data e.g. a digital elevation model
- National Character Area profiles (Natural England)
- Landscape Character Assessments
- Land cover maps e.g. Land Cover Map 2015 (Centre for Ecology and Hydrology)
- Habitat maps e.g. Natural England's Priority Habitat Inventory or local phase one habitat surveys
- Species presence and distribution data e.g. National Biodiversity Network Atlas data
- Woodland – from National Forest Inventory (Forest Research)
- Designated sites e.g. Sites of Special Scientific Interest (SSSI), Natura 2000 sites and Ramsar sites
- SSSI condition data (Natural England)
- Environment Agency flood risk maps
- Environment Agency Water Framework Directive status of water bodies
- The National Heritage List for England, Scheduled Monuments and Historic Environment Records (Historic England)
- 1st, 2nd and 3rd edition OS Maps - extending back to the 1850's provide insights into the landscape before major 20th C changes.
- Access, including Countryside and Rights Of Way Act (2000) open access land and public rights of way (Local Authorities)
- Perceived tranquillity maps e.g. from Campaign to Protect Rural England
- Natural England ecosystem services maps (further detail in A4.2.7)
- Land management data e.g. location of agri-environment scheme options (Natural England)
- Any other maps that you have locally that may supplement the above, National Parks, AONBs, Biological Records Centres and Local Authorities may have useful data.

4.2 Issues to consider

4.2.1 Data quality

The models and tools, and the data they produce, **are only as good as the information upon which they are built**. When the input information has poor spatial accuracy (scale) or is lacking in information on the habitats and species in an area, the model outputs must be viewed and used with this in mind. This uncertainty might be reduced by cross-referencing different data sets, and can be supplemented by ground-truthed data and in-depth local knowledge. In fact, local knowledge is essential for interpreting the results of any analysis, as spatial data and the outputs from many of these models are decision support tools, they don't provide definitive answers and therefore network design has to draw on a range of approaches.

4.2.2 Scale and place

Generally, a combination of national and local datasets will be used to create the underlying baseline input for any model. Scale is very important: there will be outputs that work better for national scale targeting and others that are capable of providing detailed local analysis. However, it is important to understand data at a range of scales and to acknowledge that national coverage does not necessarily mean poor local scale resolution. A number of useful national data sets have a fine resolution, but others may only be useful at a much coarser scale.

The use of tools and data may also be place-specific. Some tools may be relevant in more nature-rich areas such as National Parks, National Nature Reserves or other protected areas. Others are more useful in an urban setting. Urban-rural linkages can be important for nature networks. Bringing nature in to the areas where people live, and allowing it to pass through potential barriers will often be key objectives.

4.2.3 Complexity vs. simplicity

A very complex model might not always give a better result than a simpler one; sometimes an indication of the situation is good enough to aid spatial planning. Delving deeply into complicated frameworks or models might not be as useful as gaining a common understanding and overview agreement on the assets within an area. Using four or five key sources of information might be a good place to start, rather than using 20-30 different datasets or a complex model. Complex models often have the added disadvantage of requiring more complex data, more time consuming analysis and specialist skill sets by the user. In addition, as tools increase in complexity, the transparency of how they work decreases and the underlying assumptions are likely to increase. This can result in masking the uncertainty in the model results. It is worth stating again that the quality of the input data will affect the model results, no matter how complex the model is.

4.2.4 Uncertainty and action

There are a wide range of factors that influence the creation, enhancement and success of nature networks. As such, one needs to be aware that there are many complex interactions to take into account and that the future is, of course, uncertain. The natural and human environment is highly complex making it impossible to consider or predict the results of land management. At some point modelling and analysis of the problem needs to move to practical action on the ground, but bearing in mind the remaining uncertainties and potential risks.

There is also a specific need to consider range-expanding and range-contracting species, current levels of habitat fragmentation and condition as well as changing ecosystem processes. Many models won't cope with this complexity or dynamism. It is important to remember that the tools we present here will usually only provide a snapshot in time and not a complete picture or solution for your area or landscape.

4.3 Background to map-based models and tools

Models and tools can be viewed on a spectrum from simple to complex. The simpler ones set out basic principles and questions, or help identify problems (e.g. simple vulnerability assessment). More complex ones take connectivity and meta-population approaches. Others assess possible solutions and identify specific areas for action (e.g. conservation prioritisation software such as Marxan). Natural capital tools with an ecosystem focus can provide information on attributes or environmental variables, such as soil characteristics, useful in the design of nature networks, which are beneficial for both wildlife and people. We will provide information on some of each; Table 4.3 gives a brief introduction to which tools are potentially helpful. The variety may appear confusing but we hope that the information in this chapter will help to clarify their different uses.

Table 4.3 A summary of useful tools for nature network design

Principle being addressed	Model/ Data	Key benefits	Availability
Climate change adaptation	National Habitat Networks Maps (2018)	National level Habitat Network Mapping for England. Highlights key areas to create and restore habitats and reduce fragmentation.	Data are available as separate habitat networks for many priority habitats or as an integrated product. Available on an open licence.
	National Biodiversity Climate Change Vulnerability Assessment (NBCCVA)	National scale habitat vulnerability analysis.	Available on an open licence.
	Climate change refugia maps	Identifies the locations of climate change refugia nationally.	Available on an open licence.
	Species Risks and Opportunities maps	Large number of GB-scale climate envelope models for 3000+ species.	Available on an open licence.

Principle being addressed	Model/ Data	Key benefits	Availability
Connectivity & fragmentation	National Habitat Networks Maps (2018)	Habitat Mapping for England. Highlights key areas to reduce fragmentation.	Data are available as separate habitat networks for many priority habitats or as an integrated product. Available on an open licence.
	Condatis	Assesses long distance migration probability, measuring flow through the landscape to help identify best places for habitat creation.	Requires expert modelling.
	National Biodiversity Climate Change Vulnerability Assessment	Structural habitat fragmentation assessment	Available on an open licence.
	Forest Research least-cost network approach	Provides least cost path connectivity assessments.	Requires expert modelling.
	RangeShifter	Assesses species movement across a landscape, based on habitat suitability, dispersal ability and aspects of population dynamics.	Requires expert modelling.
Habitat Creation & Restoration	National Habitat Networks Maps (2018)	Habitat Mapping for England. Highlights key areas to create and restore habitats.	Data are available as separate habitat networks for many priority habitats or as an integrated product. Available on an open licence.
	Habitat Potential maps	Provides indication of the potential for an area to support specific habitat creation.	Uses soil and other data, which has licence restrictions. Contact Natural England via details below.

Principle being addressed	Model/ Data	Key benefits	Availability
Natural Capital and Ecosystem services	Carbon storage and sequestration maps	Climate change mitigation contribution from the natural environment.	Uses soil and other data, which has licence restrictions. Contact Natural England via details below.
	Natural England Natural Capital Atlases	Atlases at national and county/city scales of ecosystem assets and services	Published by Natural England in 2020: Wigley *et al.* 2020.
	Natural England & CEH Natural Capital maps	Maps of natural capital providing ecosystem services.	Maps and data available from https://eip.ceh.ac.uk/naturalengland-ncmaps (Accessed 20/1/20)
	Natural Capital Assessment Gateway	A web-based gateway to local natural capital assessments and ecosystem services mapping projects.	Availability varies between local mapping projects, see https://ecosystemsknowledge.net/natural-capital-assessment-gateway (Accessed 20/1/20)
Spatial Prioristsation Tools	Zonation Marxan	These can identify the most important places to focus effort and achieve multiple objectives.	Complex tools with high demands for technical skills and data. The tools are freely available online.

4.4 Practicalities

4.4.1 Technical expertise required

As highlighted in Table 4.3 above, many of the tools and data summarised in this section will require specific technical expertise e.g. use of GIS (Geographic Information System) software and/or some level of technical understanding of ecological networks concepts and tools. This may be available within your organisation, team or project, or you may have to commission this from elsewhere e.g. a GIS team within your organisation or your partnership. Training in the use of GIS software may be required for staff in order to get the most from the functionality of web-based tools. The need for technical expertise should be considered in any work that aims to use spatial tools and data.

4.4.2 Updating

Many of these tools and data can only provide a current description or projection for a snapshot in time or a specific scenario (although in some cases many snapshots or scenarios can be produced to show how a project might progress). In many cases the data products will still be very useful, but it is important to understand this limitation. It is also important to be aware of how regularly the contributing datasets are updated (e.g. land cover, site condition, land management activity), and thus to understand the potential for the results to be 'out-of-date', or of different ages, and whether this matters. Therefore you may want to consider whether there is a need to schedule updates to the assessments you do, using these tools. However, as many of the datasets, and the results from these spatial tools, can only provide an indication of the situation for an area, due to associated uncertainties and incompleteness, and because data updates are often relatively small, the snap-shot results will often be sufficiently valid for understanding the general picture of the natural assets in a place, and how they might change as a nature network develops.

4.4.3 Incorporating local knowledge

Spatial data and tools do not provide the definitive answer as to where to place nature networks. They are often very useful as decision support tools or discussion starters; but the inclusion of local knowledge, expertise and experience is crucial. Any framework or project must be designed to utilise both national and local knowledge and information and, as always, it is important to work closely with partners to provide the most useful tools to aid these discussions.

4.4.4 Data needs

For some tools and models you may require other types of information than the spatial data listed above in Box 4.1. This can include information about the ecology of a species that you are interested in. For example, habitat preferences at different life cycle stages or their dispersal abilities, i.e. how far they can travel and what kinds of habitats they will use or travel through.

Here are some examples of the types of ecological data that may be required:

- **Habitat preferences** – Species have different requirements regarding the habitats they live in and move through. They are likely to have different requirements at different times of the year or lifecycle. You may need to know these requirements to use some of the models. Their ability to move through or otherwise use different land use types could also be useful information. Furthermore, species will have different responses to the edges of habitat patches, some being more sensitive to 'edge-effects' than others, or some being specifically associated with areas where different habitats are adjacent to each other. Again, there have been very few studies to determine this kind of information so you might need to model a range of reasonable values.

- **Species dispersal information** – you may need this type of information for species relevant to your area. You will get these data from previous studies on the species of interest, however, the existence of this type of data is limited. What you will probably find is that you will make an informed estimate or range of estimates based on the studies of similar species. Or you can run a series of different analyses using different dispersal distances in order to give you a range of results that indicate the likely connectivity of your networks for a range of species with different dispersal abilities.

- **Other ecological traits** – this information could include the feeding or nesting needs of species or their reproductive strategy (many or few offspring).

- **Topographical information** – The topography of an area will affect its ecology and will also contribute to its resilience to climate change. Having information about how varied an area's topography is useful in determining where you might want to restore or create habitat. For example, species may have specific requirements with regard to moisture, hydrology, natural processes and microclimate. A varied topography can also provide more niches for species. An example of a response to climate change may be that a species that currently occupies south-facing slopes, may start to utilise north-facing slopes as the climate warms. Digital terrain models and LiDAR data are examples of topography mapping that could be useful.

- **Species climate envelope modelling** – These are unlikely to be data you will create yourself, but may be data you will use. Species climate preferences are used alongside climate change projections (e.g. UKCP18[22]) to show how climate suitability may change over time – some areas may become less suitable and other more suitable. It is important to remember that most of this type of analysis does not include any information on the ability of a species to move in to any new 'climate space', as there might be barriers to movement. Furthermore, they may not take into account the availability of suitable habitat, or how the habitat might change with climate change. A project to model species potential range movement in response to climate, the Species Risks and Opportunities project undertook such modelling for 4000 species in England and is described below (Pearce-Higgins *et al*. 2017). Other UK examples of projects that modelled species climate envelopes include BRANCH Partnership (2007) and MONARCH (Walmsley *et al.* 2007).

4.5 Available map-based tools and models

This section provides a short summary of a selection of available models or tools useful in the design of ecological networks for wildlife and people. Please see Appendix 4 for more information:

4.5.1 Maps

4.5.1.1 *Climate change refugia maps*: (Suggitt *et al*. 2014; Appendix A4.2.1). These data identify geographic areas that are likely to be important for the maintenance of biodiversity in a changing climate. The term 'refugia' is used here to describe areas that are likely to be somewhat sheltered from change or relatively climatically stable in the future and so enable species to persist for longer, despite climate change making surrounding areas potentially unsuitable. Properties of the landscape, identified in the literature as contributing to refugium potential, were modelled at 100m resolution for England and summarised at the scale of 10 x 10 km grid squares (e.g. Fig. 4.5.1.1). The local survival and extinction of over a thousand species that changed their range over the past four decades was modelled against environmental properties shown to influence refugium potential e.g. microclimate heterogeneity. The resulting maps indicate areas that are inherently more vulnerable to change and others which are less so; such refugia may provide important contributions to a nature network. Fig. 4.5.1.1 shows a map of refugia potential data for England at a 10 km^2 scale. The darker areas have the highest refugia potential, having environmental variables, such as high mean elevation, cooler microclimates, high water availability, lower levels of agricultural intensity and lower levels of historical climate change, that are indicative of refugia. The lighter areas contain fewer of these refugia indicators.

[22] UK Climate Projections 2018: https://www.metoffice.gov.uk/research/collaboration/ukcp

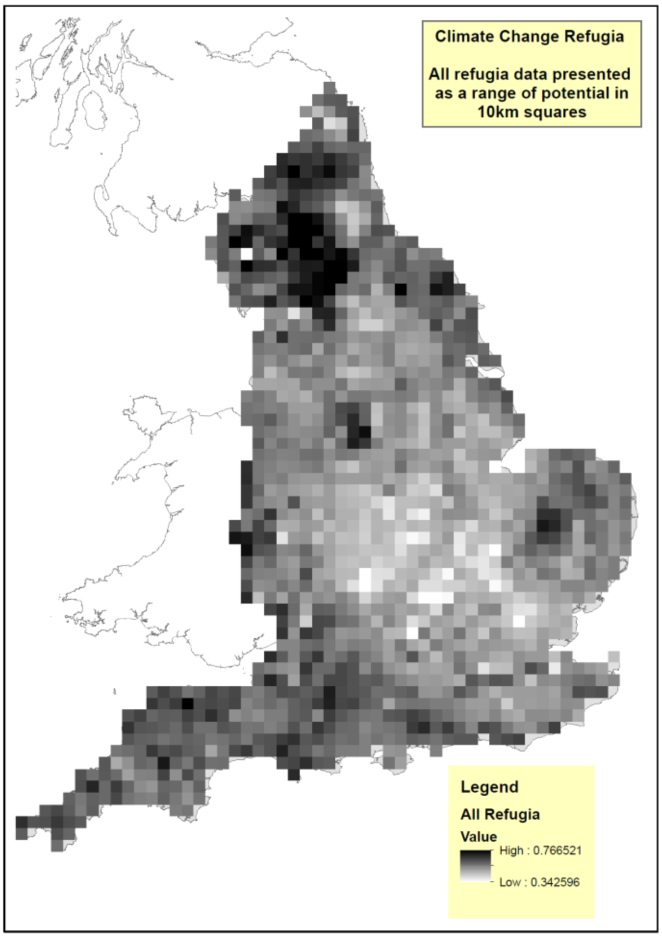


Figure 4.5.1.1 Climate change refugia map for England (see text for details).

4.5.1.2 *Assessment of climate change risks and opportunities for species*: (Pearce-Higgins *et al.* 2015, 2017; Appendix A4.2.2). This project used the latest modelling techniques and analytical frameworks to explore how changes in climate suitability as a result of projected climate change might affect the distributions (and for migratory birds, their population sizes) of species. The analysis was undertaken for 3000+ species of a wide range of terrestrial taxa (from vascular plants and bryophytes to spiders and beetles and birds) and assessed the potential risks within their existing ranges as well as opportunities that might be provided in new areas. The spatial outputs from this project are maps showing the current and projected changes in the climate suitability for a species in both its historical range and outside its historical range.

Fig. 4.5.1.2 provides an example of the modelled results for the northern brown argus butterfly *Aricia artaxerxes*, showing the probability that this species will be found in a 10 km grid square, under a future global climate change scenario of +2^{0}C warming. The modelling was based on its current distribution and its relationship to a number of climatic variables. It is important to note that other variables that influence species distributions, such as habitat and land−use change, were not accounted for in the modelling process.

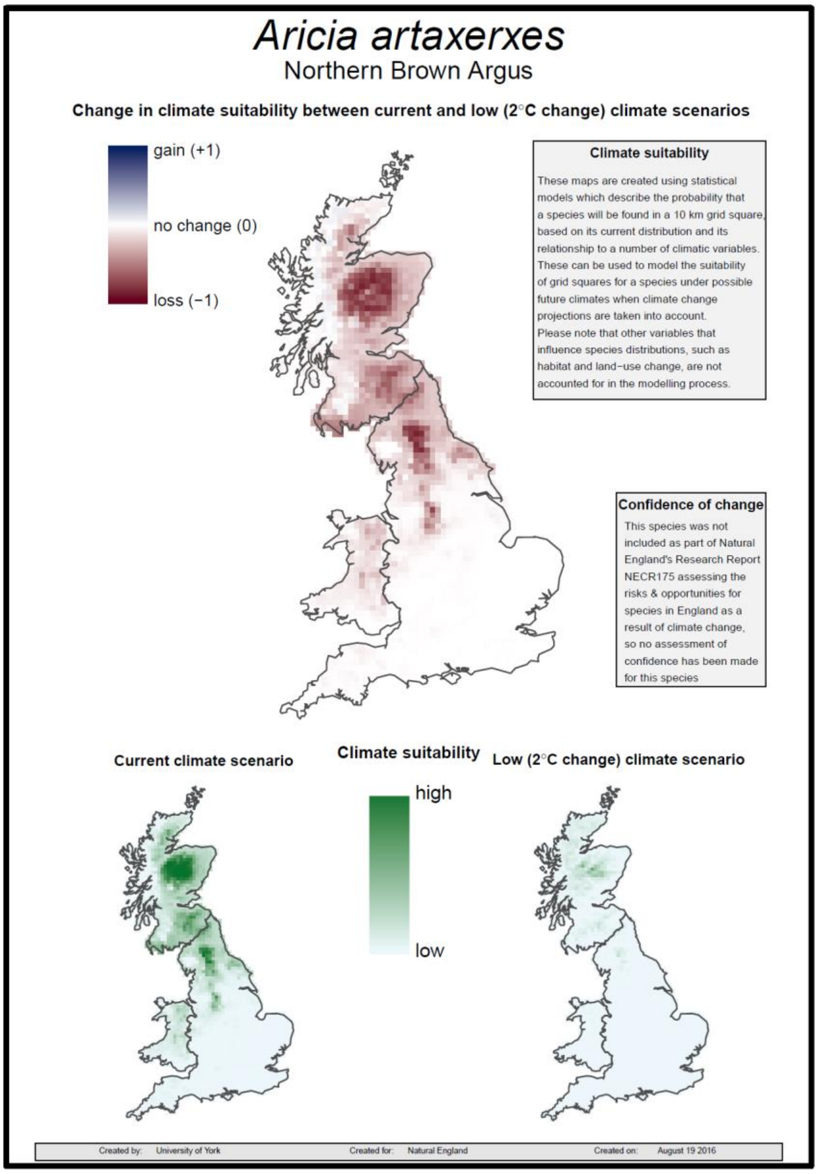


Figure 4.5.1.2 Modelled change in climate suitability for northern brown argus[23], between current and low (+2^{0}C) climate change scenarios (*Source: Pearce-Higgins* et al. *2015*). © Natural England 2019. Data from the Butterflies for the New Millennium recording scheme and National Moth Recording Scheme were provided courtesy of Butterfly Conservation. Contains public sector information licensed under the Open Government Licence v3.0.

[23] The species distribution data originates from the Butterflies for the New Millennium recording scheme and National Moth Recording Scheme, and was collated by the Biological Records Centre (BRC) on their behalf. BRC receive support from the Joint Nature Conservation Committee and the UK Centre for Ecology & Hydrology (via the Natural Environment Research Council award number NE/R016429/1 as part of the UK-SCAPE programme delivering National Capability). We are indebted to the volunteer recorders, and organisations who provide data to the schemes, and to the volunteer scheme organisers and staff members who support the schemes. Contact details for the schemes are available on the BRC website [https://www.brc.ac.uk/recording-schemes].

4.5.1.3 *Habitat Potential maps*: (Morgan et al. 2016; Appendix A4.2.3). These maps show areas where appropriate conditions exist to support the creation of habitat, i.e. the area has qualities relating to a particular habitat that suggest that creation and/or restoration is likely to be successful. Habitat potential is assessed through the identification of physical conditions, often soil type, that support the creation of particular habitats. Fig. 4.5.1.3 shows an example habitat potential map for calcareous grassland.

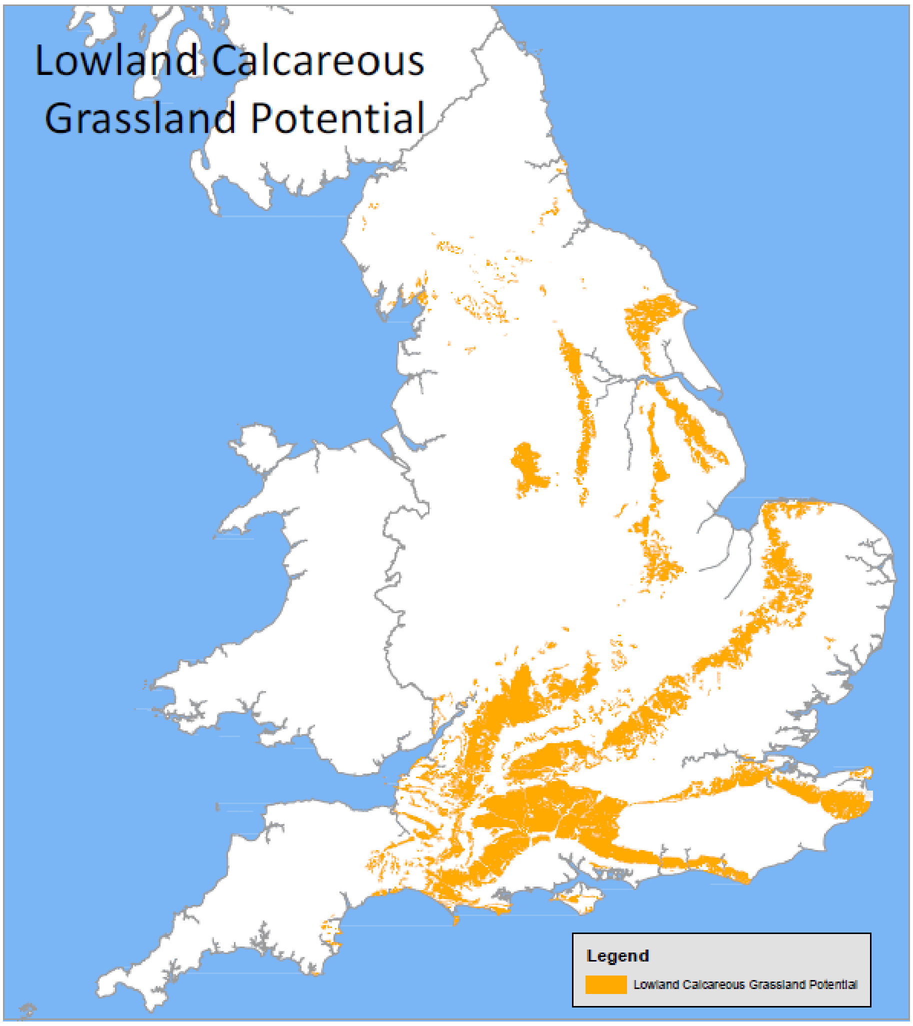


Figure 4.5.1.3 Example of a Habitat Potential Map for Calcareous Grassland. © Natural England 2019. Soils Data © Cranfield University (NSRI) and for the Controller of HMSO 2019. © Crown Copyright and database rights 2019. Ordnance Survey 100022021.

4.5.1.4 *National Habitat Network (NHN) maps*[24]: (Edwards *et al*. 2018; Appendix A4.2.4). These are a set of national scale maps based on the Natural England Priority Habitat Inventories that combine data to represent a national habitat network for priority habitats. These national habitat network maps can be used to contribute to the development of a local nature network, alongside local information, data and knowledge. They can assist in identifying priorities for habitat restoration and creation in order to enlarge existing habitat patches and reduce fragmentation.

Fig. 4.5.1.4a illustrates the NHN components that together provide suggested locations for habitat creation and restoration priorities for an example area of Lowland Heathland. The **Primary Priority Habitat** shows the current presence of a priority habitat for which the network is being developed. The **Associated Habitats** shows the location of other priority habitat types that form a mosaic or an ecologically coherent group with the primary priority habitat. **Habitat Creation-Restoration** areas show locations where work is underway to either create or restore the primary habitat. **Restorable Habitat** shows areas of semi-natural habitat where the primary habitat is likely to be present in small quantities or in a degraded or fragmented form and which are likely to be suitable for restoration. The **Network Enhancement Zone 1** is land in close proximity to existing patches of primary and associated priority habitats where improving the biodiversity value would be beneficial and would contribute towards greater ecological resilience of the existing habitat patches. Within Zone 1 conditions are likely to be suitable for creation and restoration of the primary priority habitat. Factors affecting suitability include: proximity to primary habitat, land use (urban/rural), soil type, slope and proximity to coast. Action in this zone can help to expand and join up existing habitat patches and improve the connections between them. **Enhancement Zone 2** is land connecting existing patches of primary and associated habitats which is less likely to be suitable for creation of the primary priority habitat. However, other actions that improve the biodiversity value of the land, such as increasing green infrastructure provision, in this zone can help buffer existing habitat patches and improve connections between them. The **Fragmentation Action Zones** help highlight smaller fragmented areas of existing habitat that have the potential to be enlarged or joined with other habitat patches. It highlights priorities for habitat restoration and creation that could reduce this fragmentation.

Fig. 4.5.1.4b shows an example of the ‘Combined Habitat Networks Map’. This map aims to help identify potential opportunities and to gain a fuller picture across a landscape through considering a wider functional mosaic of habitats rather than a single priority habitat. The Combined Habitat Networks Map is comprised of the same component parts of the individual National Habitat Network maps and distinguishes between the different priority habitats using different shades of green.

[24] https://naturalengland-defra.opendata.arcgis.com/datasets/fceb93850462454ab3fb5accea2be35b_0

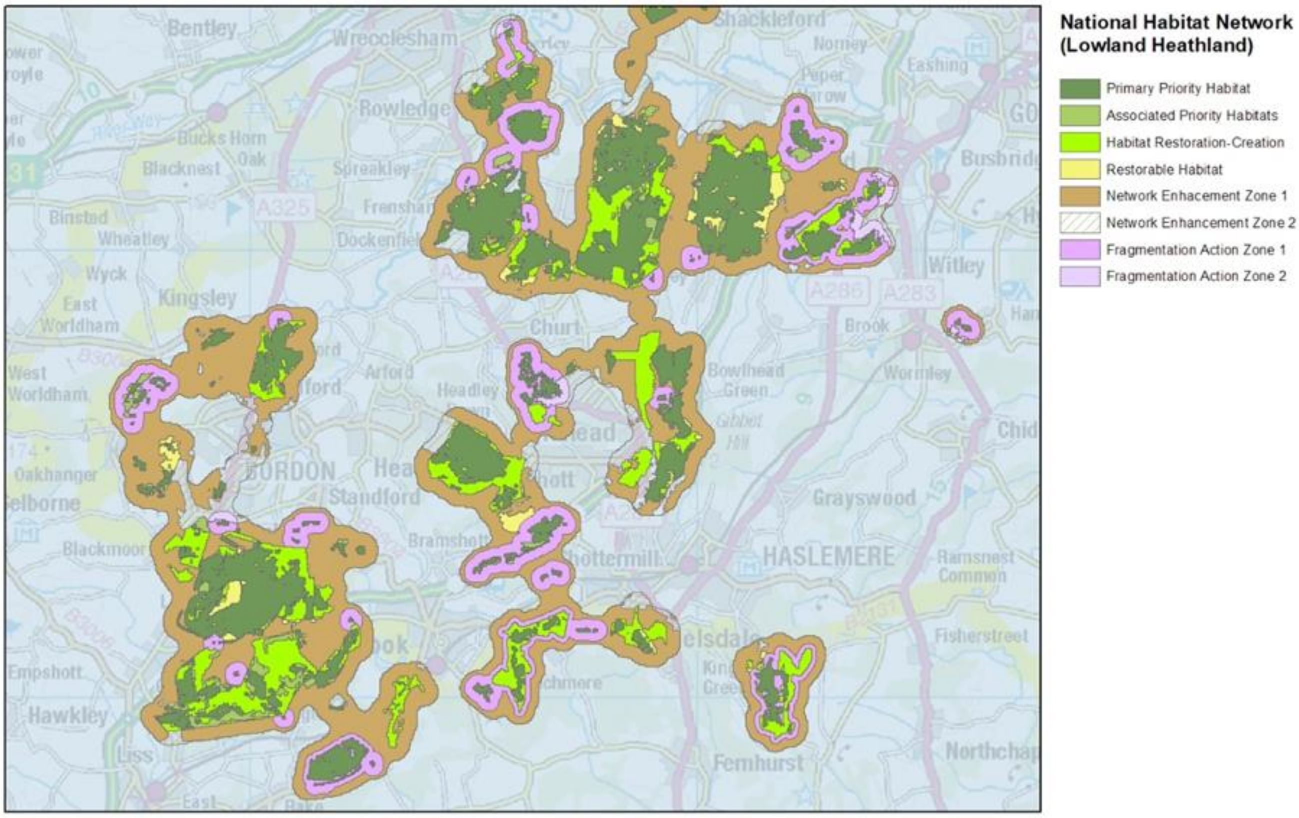


Figure 4.5.1.4a National Habitat Network Map - Single Habitat Example. © Natural England 2019. Soils Data © Cranfield University (NSRI) and for the Controller of HMSO 2019. © Crown Copyright and database rights 2019. Ordnance Survey 100022021. Contains public sector information licensed under the Open Government Licence v3.0.

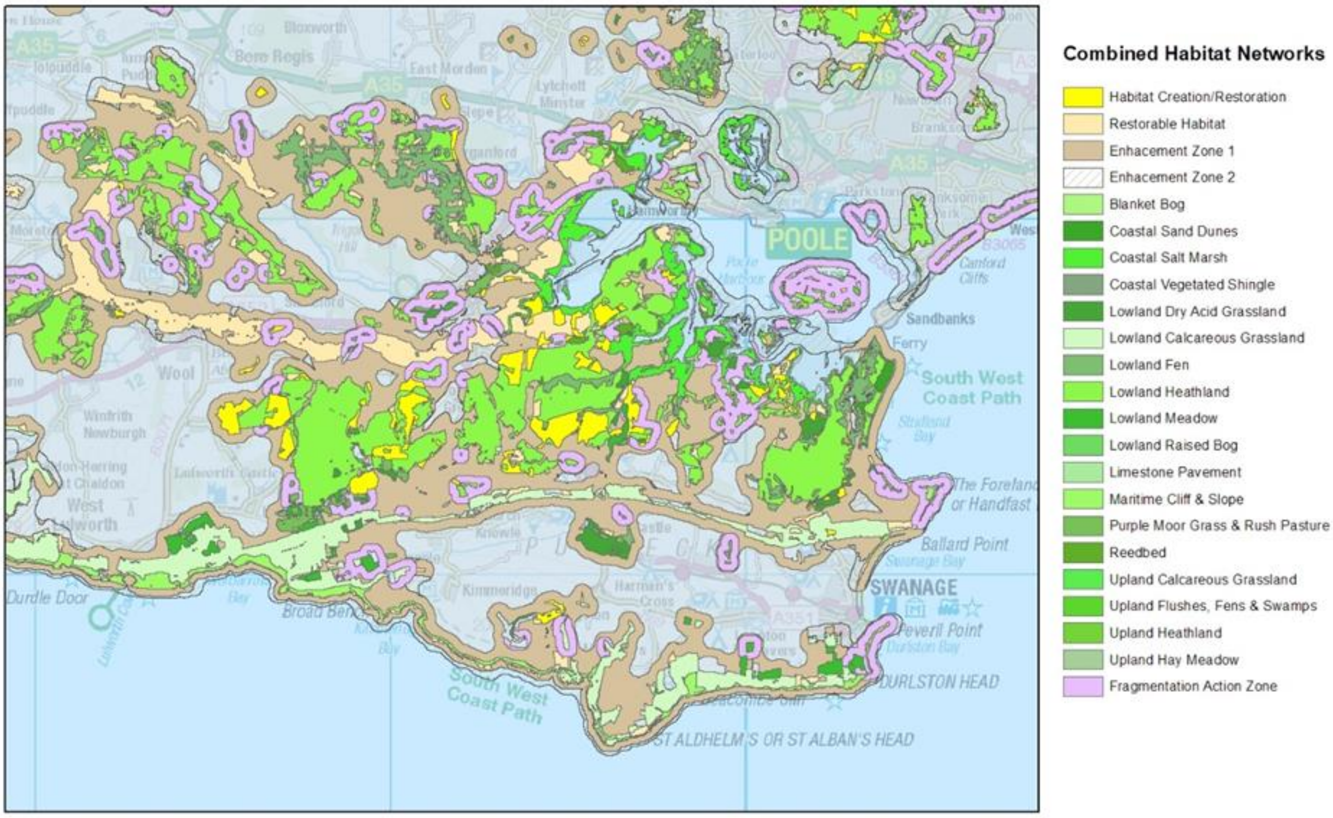


Figure 4.5.1.4b National Habitat Network Map - Combined Habitat Example. © Natural England 2019. Soils Data © Cranfield University (NSRI) and for the Controller of HMSO 2019. © Crown Copyright and database rights 2019. Ordnance Survey 100022021. Contains public sector information licensed under the Open Government Licence v3.0.

4.5.1.5 *Carbon storage and sequestration maps*: (Natural England/Amec unpublished; Appendix A4.2.5). These maps identify both Carbon Storage and Carbon Sequestration Priorities. The Carbon Storage Priority areas have high carbon densities that require protection to prevent further carbon loss. The Carbon Sequestration Priority areas show where carbon storage could be increased with positive land use change (e.g. when changing from arable to grassland, carbon emissions from underlying peat is substantially reduced).

Fig. 4.5.1.5a shows Carbon Storage Priorities for England, where high values represent the presence of a high carbon peat based soil of significant depth (over 1.5m), probably due to relatively little disturbance over time and being under positive management for carbon storage (e.g. undrained semi-natural habitat). Medium values show where there was peat soil of significant depth (over 1.5m) but where land management practices have reduced the original peat depth and the capacity of the soil to store carbon (e.g. grazed wet grassland). Low values represent where the soil has a lower amount of stored carbon, or because much has already been lost due to extended periods of incompatible land management (e.g. arable management on peatland soils).

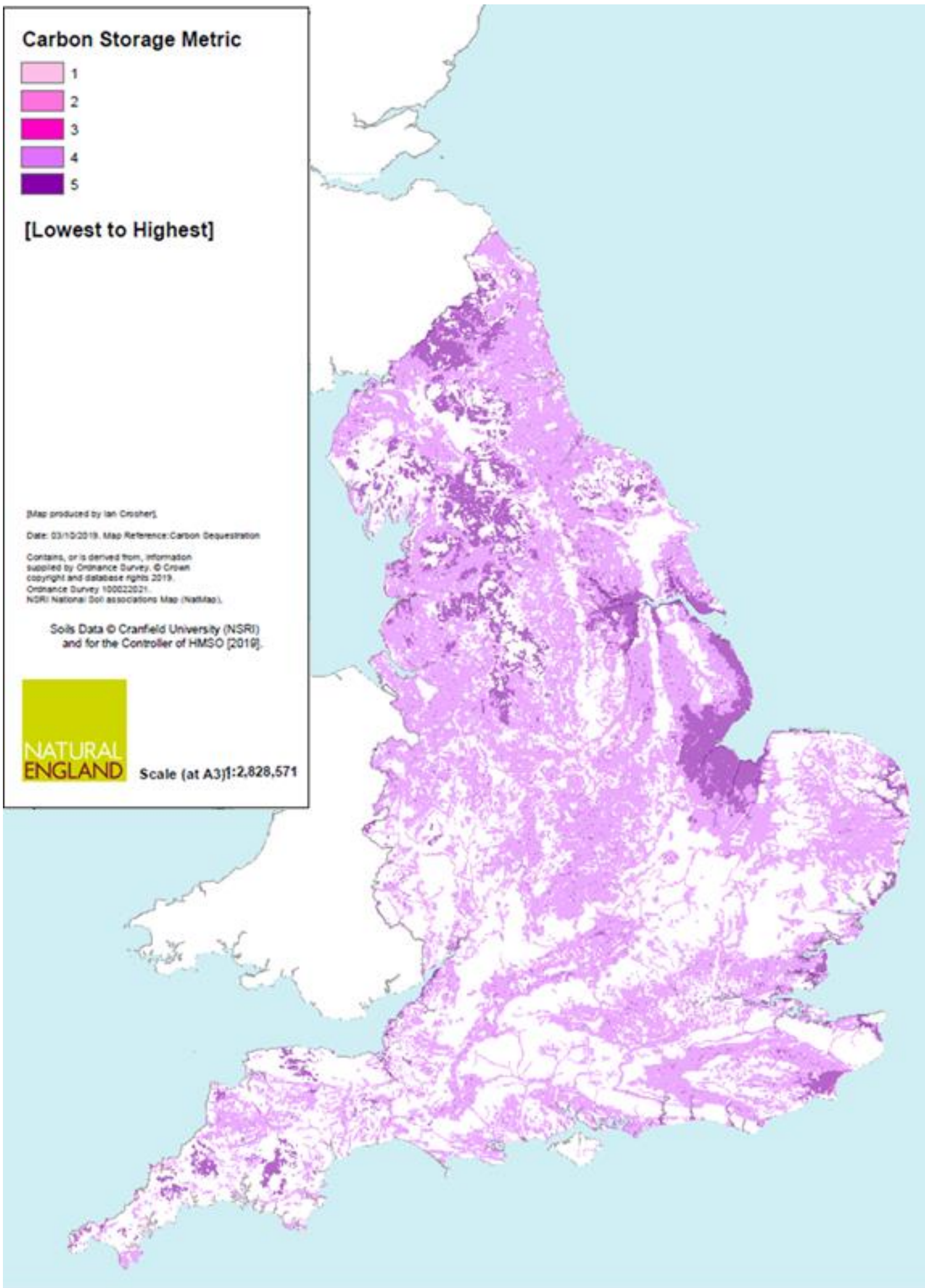


Figure 4.5.1.5a Carbon Storage Priority Map (Source: Spatial Prioritisation of Land Management for Carbon, Natural England/AMEC). © Natural England 2019. Soils Data © Cranfield University (NSRI) and for the Controller of HMSO 2019. © Crown Copyright and database rights 2019. Ordnance Survey 100022021.

Fig. 4.5.1.5b shows where carbon storage could be increased with positive land use change. High values indicate areas that are losing carbon to the atmosphere at a very high rate through oxidation (e.g. arable management on peatland soils), where a change in land use could significantly reduce carbon loss. Medium values highlight areas with moderate carbon loss and with potential to reduce this rate of loss (e.g. improved grassland over peatland soils). Low values show areas with low carbon storage capacity, or are already under sympathetic management (e.g. wetland habitats under restoration), or areas which have been heavily degraded by land management practices.

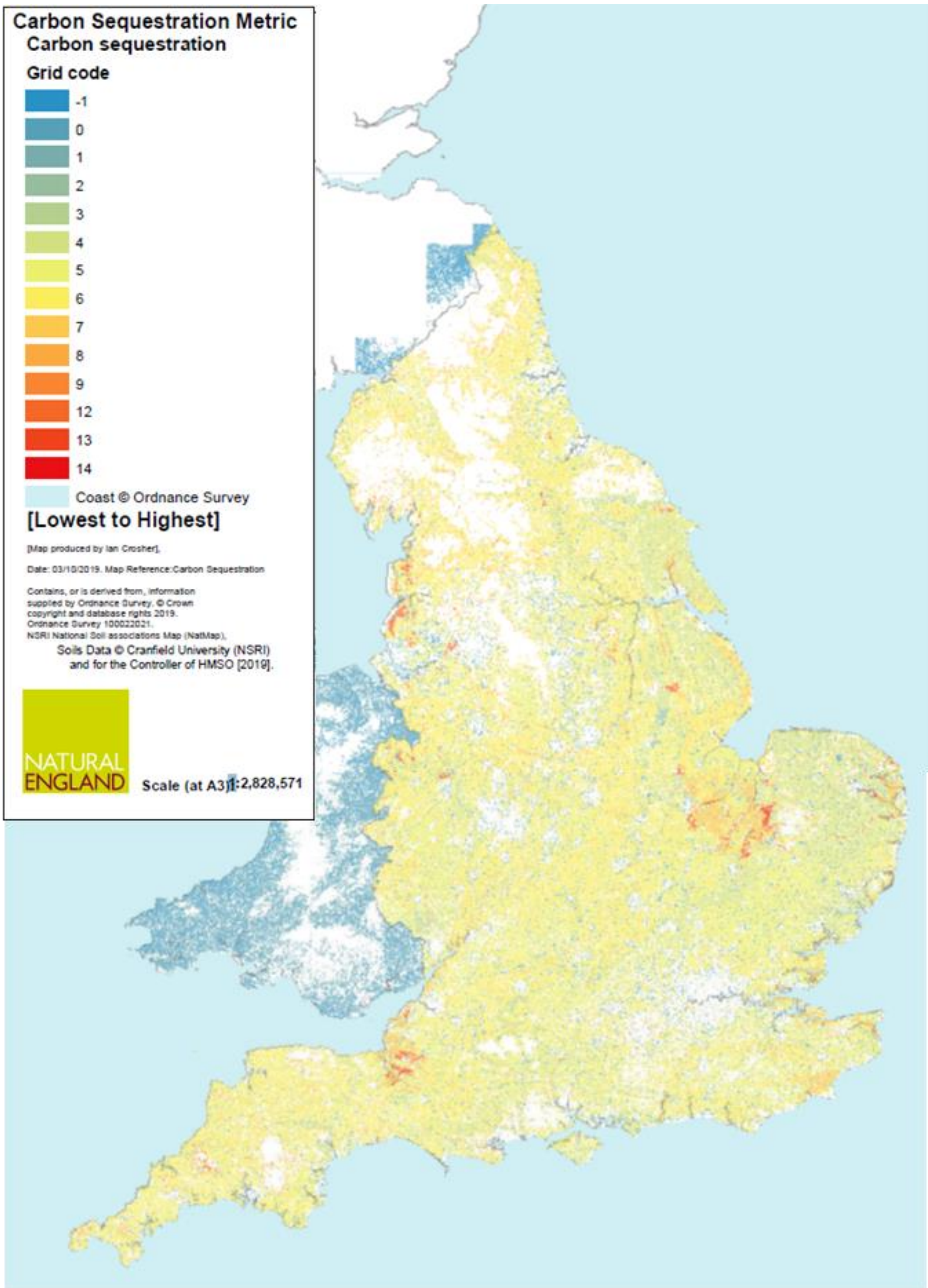


Figure 4.5.1.5b Carbon Sequestration Priority Map (Source: Spatial Prioritisation of Land Management for Carbon, Natural England/AMEC). © Natural England 2019. Soils Data © Cranfield University (NSRI) and for the Controller of HMSO 2019. © Crown Copyright and database rights 2019. Ordnance Survey 100022021.

4.5.1.6 *Natural Capital Mapping*[25]: (CEH and Natural England; Appendix A4.2.6). This provides publically accessible 'off-the-peg' maps of natural capital in England, without the need for additional data input or modelling. Ten maps are available: soil carbon, soil pH, soil nitrogen, soil phosphorus, soil invertebrates, soil bacteria as well as headwater stream quality (based on invertebrate assemblages), plant indicators of good habitat condition, above ground carbon and nectar plant diversity for bees. The maps are accessible to view or download as high quality images or GIS layers. Users can take a map away and combine it with other GIS layers, or cut it to the part of the country that they are interested in. An accompanying text details what the map shows and how it has been produced. Maps show mean value for a 1 km grid square and standard error from the mean, showing uncertainty.

As an example of these maps, Fig. 4.5.1.6 shows mean estimates of total abundance of invertebrates in topsoil (0-8 cm depth). Soil invertebrates have an important role in soil processes. This includes storing, filtering and transforming nutrients, as well as promoting plant growth. Soil invertebrates are fundamental to maintaining soil quality, which underpins almost all other regulating ecosystem services. This map was produced by using measurements of total number of invertebrates extracted from soil cores in the Centre for Ecology & Hydrology's Countryside Survey in 2007 (Morton *et al.* 2011) at 927 sample locations across GB within 238 1 km squares. Measurements were extrapolated up to a national level using statistical analysis. This extrapolation was based on the total number of invertebrates extracted associated with a combination of habitat type and soil parent material (the geological material, bedrock, superficial and drift, from which soil develops).

[25] https://eip.ceh.ac.uk/naturalengland-ncmaps (Accessed 8/2/19)

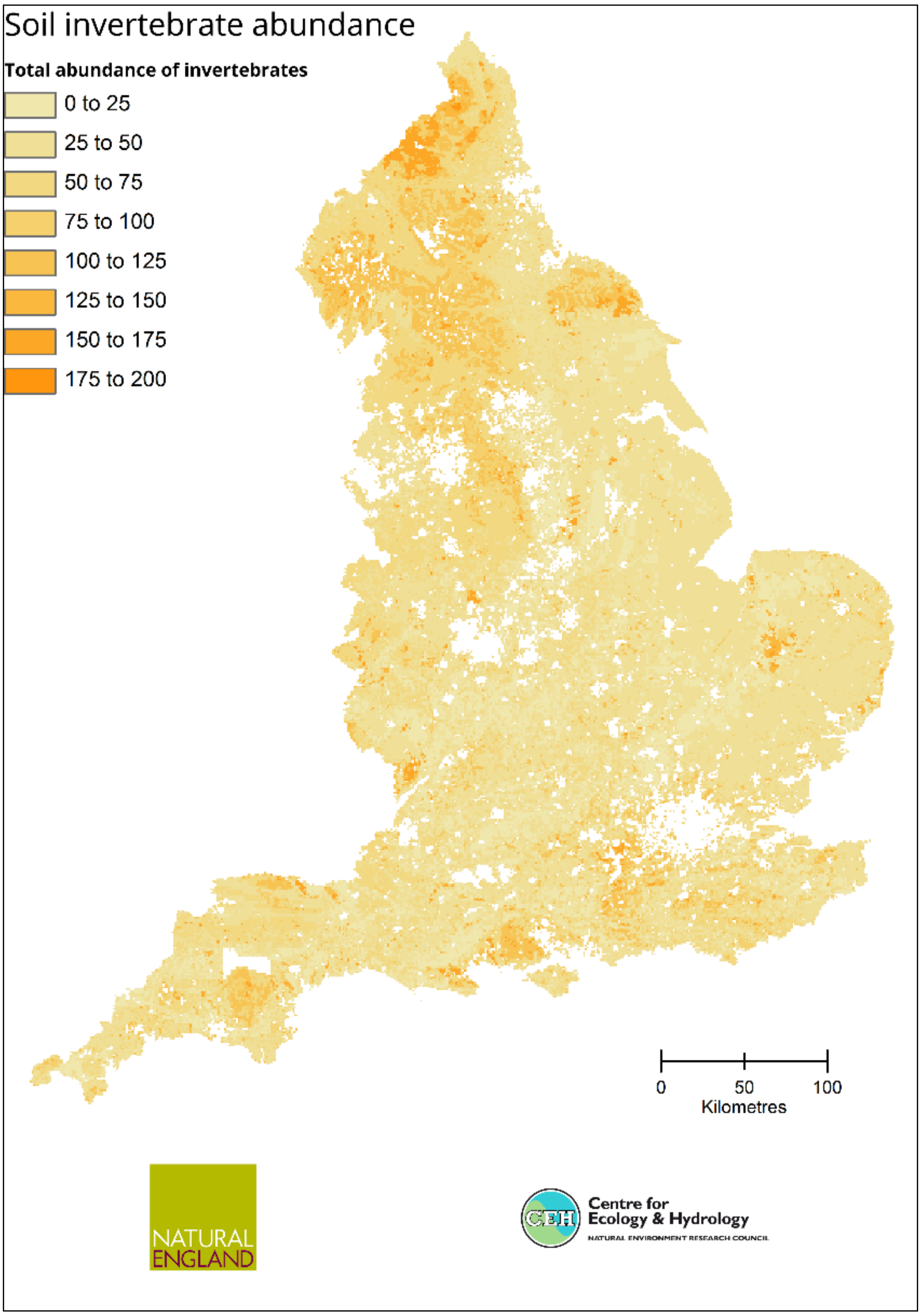


Figure 4.5.1.6 Natural Capital map of invertebrate abundance in topsoil (Source: Natural England and CEH Natural Capital Mapping *https://eip.ceh.ac.uk/naturalengland-ncmaps* (Accessed 8/2/19)). Data from: Henrys, P.A.; Keith, A.M.; Robinson, D.A.; Emmett, B.A. (2012). Model estimates of topsoil invertebrates [Countryside Survey]. NERC Environmental Information Data Centre. http://doi.org/10.5285/f19de821-a436-4b28-95f6-b7287ef0bf15 (Accessed 20/1/20). Contains data supplied by Natural Environment Research Council. Contains public sector information licensed under the Open Government Licence v3.0.

4.5.1.7 ***Natural Capital Atlases***: (Wigley *et al.* 2020; Appendix A4.2.7). The Natural Capital Atlases provide maps of ecosystem asset quantity, quality and location and, where possible, ecosystem services for England, English counties and cities. They map the indicators identified in *Natural Capital Indicators: for defining and measuring change in natural capital* (Lusardi *et al.* 2018). This report used logic chains to systematically identify the properties of the natural environment that underpin the provision of ecosystem services. An example page from an atlas is shown in Fig. 4.5.1.7.

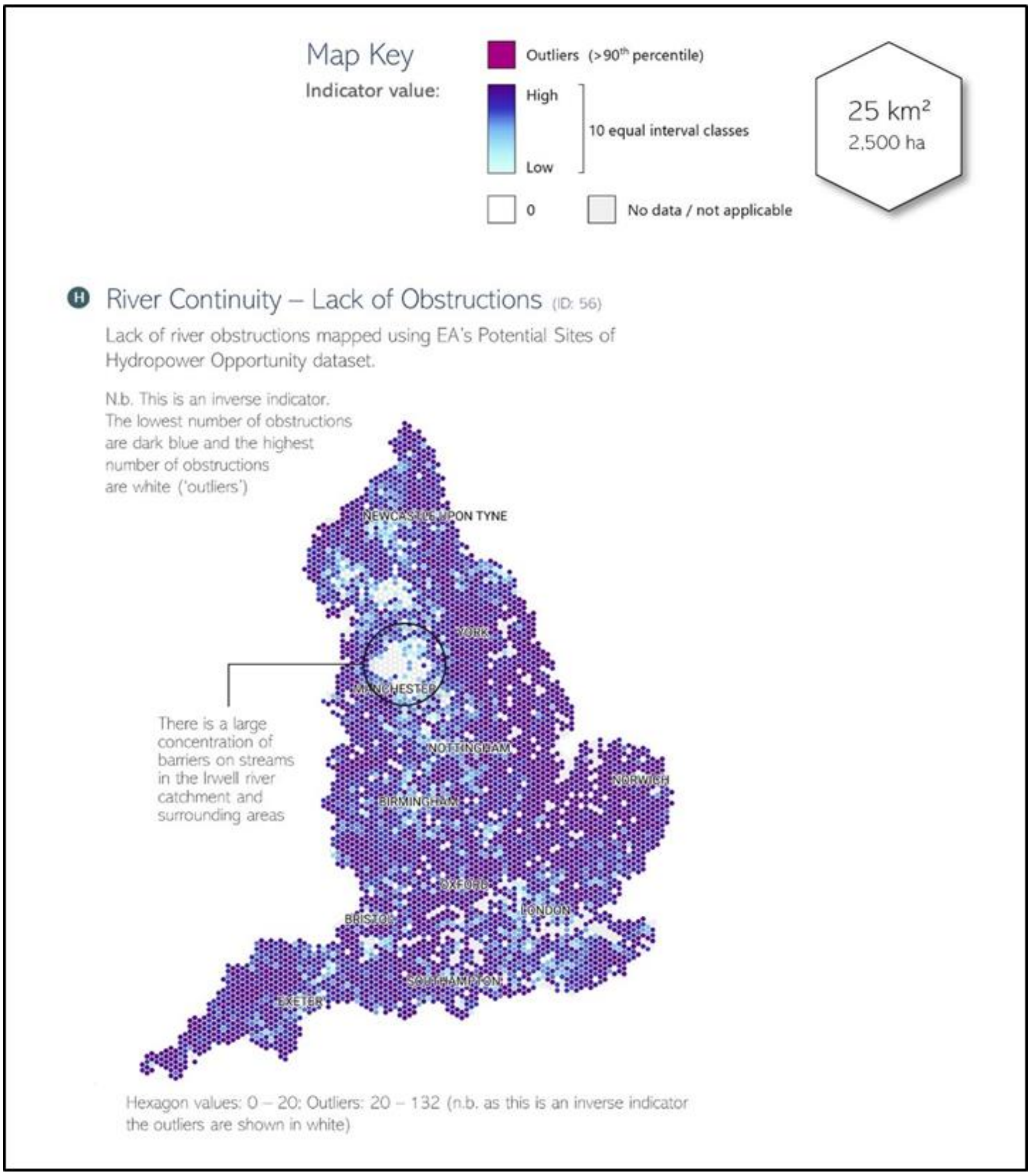


Figure 4.5.1.7 Natural Capital Atlas map of river continuity. River continuity measures lack of artificial obstructions such as dams and weirs which particularly affect the movement of migratory fish.

4.5.2 Models

4.5.2.1 *Forest Research least-cost network approach*: (Watts *et al*. 2010; Appendix A4.3.1). This uses a 'least-cost path' model called BEETLE (Humphrey *et al.* 2005) to assess how a species can traverse a landscape based upon the habitats and their configuration in space. This essentially means that landscapes are assessed for the arrangement of habitat patches and ease of movement between them for generic, or indicator, species, using dispersal distances, habitat preferences and barriers, to analyse the functional connectivity of landscapes. Fig. 4.5.2.1 shows an illustration of an output from this approach from Watts *et al*. (2010) of a modelled core and focal network for a broad-leaved woodland generic focal species in a landscape.

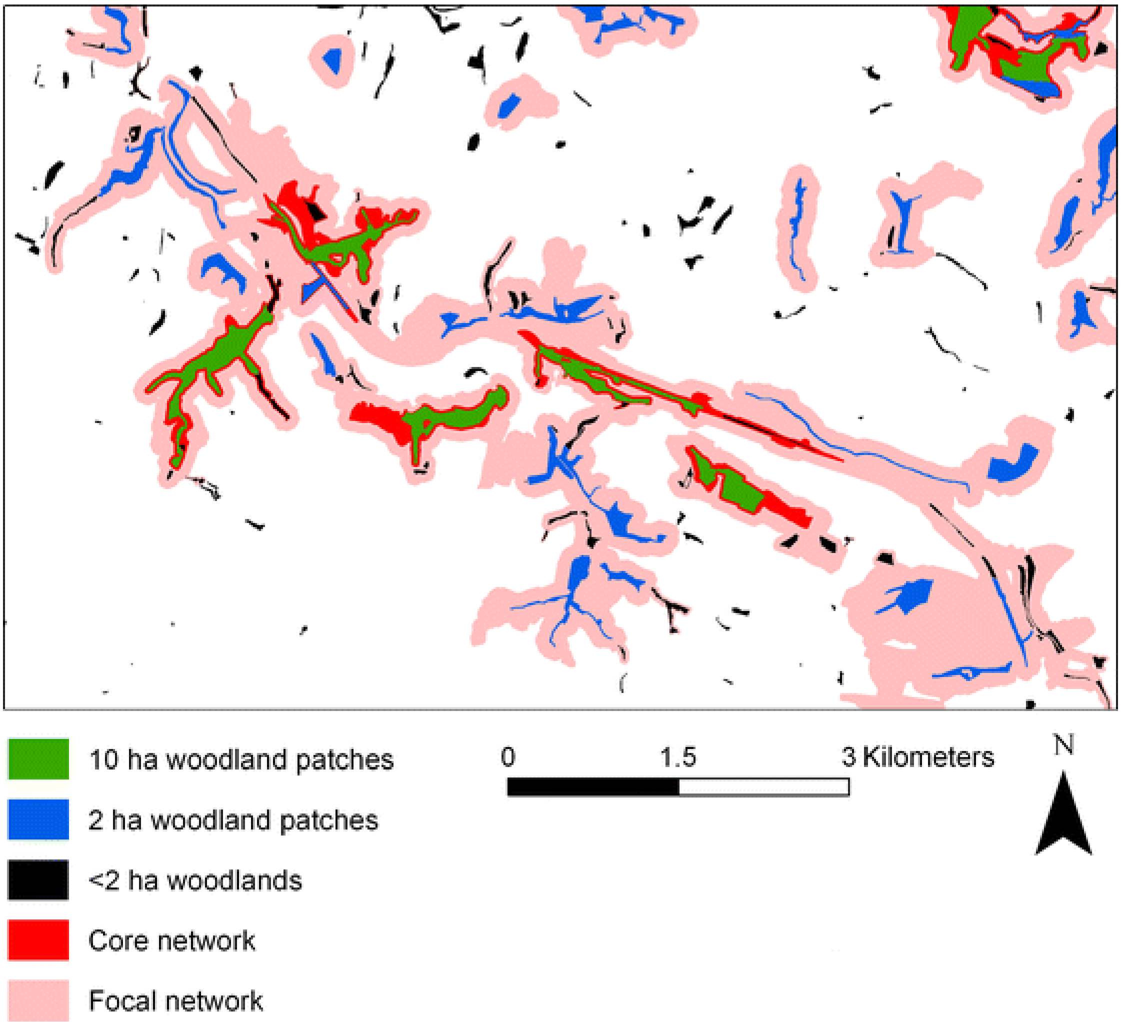


Figure 4.5.2.1 An example output from the Forest Research Least-cost approach. It represents the dispersal network for a generic woodland species that requires woodland patches of 10ha, but has a relatively low dispersal ability of 1 km. Reprinted by permission from Springer Nature Customer Service Centre GmbH: Springer Nature *Landscape Ecology* Targeting and evaluating biodiversity conservation action within fragmented landscapes: an approach based on generic focal species and least-cost networks, Watts *et al.* COPYRIGHT (2010).

4.5.2.2 *Condatis*[26]: (Hodgson *et al*. 2012; Appendix A4.3.2) is a decision support tool that helps identify the best locations for habitat creation to increase connectivity across landscapes. Condatis is based on the analogy of electrical circuit boards (wires and resistors) as a way to represent landscapes and model the way a species moves through them. The ability of species (the electrical current) to move through the landscape (the circuit board) varies depending on the configuration of the habitat patches (the wires and resistors). The tool uses a source/destination approach that replicates the movement of a species across latitudes or altitudes in response to climate change. See Fig. 4.5.2.2 for an example Condatis output.

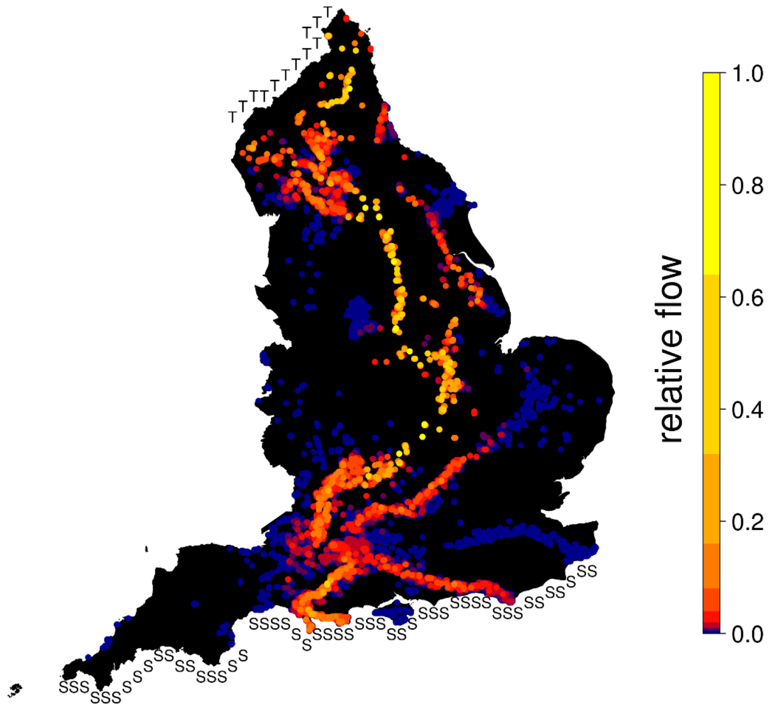


Figure 4.5.2.2 An example of a flow output from Condatis for Lowland Chalk Grassland Habitat using a 4 km dispersal distance with the source defined as the south coast of England (S) and the destination the border between England and Scotland (T), using only priority habitat data for England (Source: Alison *et al.* 2018). © Natural England 2019. Map produced using *Condatis* (Wallis, D.W. & Hodgson, J.A. (2018) Condatis 0.6.0. http://wordpress.condatis.org.uk/). Contains public sector information licensed under the Open Government Licence v3.0.

4.5.2.3 *RangeShifter*[27]: (Bocedi *et al*. 2014; Appendix A4.3.3). This tool integrates aspects of population dynamics and dispersal behaviour to model the spread of a species across a landscape. Different habitats can have different suitabilities in terms of how well a species thrives and disperses. The software shows where a species might colonise and its population densities. It needs to be run multiple times to provide an averaged picture because it has random factors built in, so each run is different. The software can address applied questions - it can be parameterised for real landscapes

[26] http://wordpress.condatis.org.uk/ (Accessed 8/2/19)
[27] http://rsdevs.github.io/RSwebsite/ (Accessed 8/2/19)

and species to compare alternative potential management interventions - or purely theoretical studies of species' eco-evolutionary dynamics and responses to different environmental pressures.

4.5.2.4 *National Biodiversity Climate Change Vulnerability Assessment (NBCCVA) and Tool*: (Taylor, Knight and Harfoot, 2014; Appendix A4.3.4). The NBCCVA tool provides a spatial assessment of the relative vulnerability of priority habitats to climate change. It identifies why areas might be vulnerable, using a series of metrics representing sensitivity, fragmentation, topography and condition, and thereby suggests which possible interventions might have the biggest impact in increasing resilience to changing climate in those areas. It is a flexible, GIS based, decision support tool, to which users can incorporate local datasets.

Fig. 4.5.2.4 shows the results of the Habitat Fragmentation metric for an example area around Morecambe Bay. The range of colours represent the range of fragmentation of habitats. This broadly shows that more semi-natural habitat in consecutive cells leads to less fragmented habitats. For example the larger contiguous areas of priority habitat are highlighted in yellow, and have low fragmentation scores. This metric can help to identify areas that may benefit from reductions in habitat fragmentation, i.e. the orange and red areas.

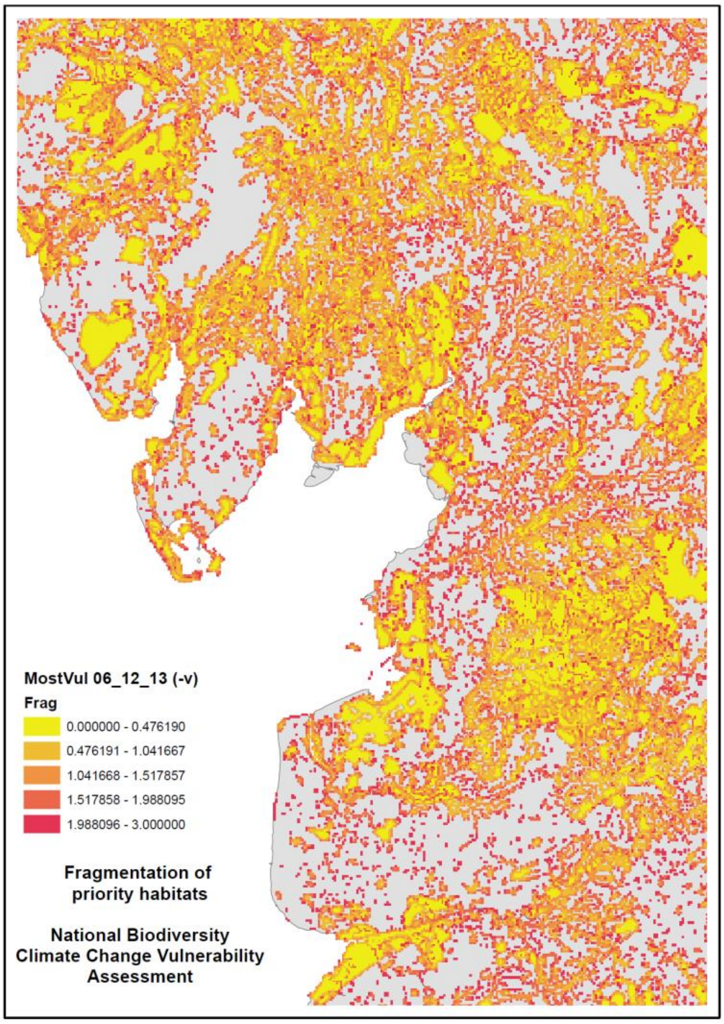


Figure 4.5.2.4 Habitat Fragmentation Metric for an example area around Morecambe Bay *(Source: NE NBCCVA).* © Natural England 2019. Contains public sector information licensed under the Open Government Licence v3.0. © Crown Copyright and database rights 2019. Ordnance Survey 100022021.

4.5.2.5 *Natural Capital Assessment Gateway*[28]: (Ecosystems Knowledge Network, University of York, Natural England, BBSRC and NERC; Appendix A4.3.5). The Natural Capital Assessment Gateway brings together information on the growing number of projects in the UK concerned with mapping and assessing natural capital and ecosystem service delivery at the local, regional or national level. It provides an interactive, searchable, map-based facility to explore projects in progress or completed across the UK.

4.5.3 Systematic Conservation Planning

4.5.3.1 *Marxan*[29]: (Ball *et al.* 2009; Appendix A4.4.1) is one of the main tools used in systematic conservation planning. Systematic conservation planning seeks to identify networks of conservation areas that are Connected, Adequate, Representative and Efficient (CARE);

- **Connected** refers to the need for the conservation areas to form a network, so that individuals and propagules can disperse through their landscapes and seascapes, and species can change their ranges in responses to local and global change.
- **Adequate** refers to the need for conservation areas that contain enough of each biodiversity element to ensure the long term persistence of biodiversity.
- **Representative** refers to the need for conservation areas that represent biodiversity in all its forms, although this generally relies on using surrogates.
- **Efficient** refers to the need to ensure that conservation area networks minimise management costs and opportunity costs to other sectors (Kukkala & Moilanen 2013).

Defining the objectives of the conservation area network is probably the key difference between systematic conservation planning and other similar approaches, and is critical for developing a shared vision and set of goals. Having defined the objectives for an area, then Marxan can be used to identify the priority areas needed to meet those goals, in a CAREful way. Importantly, the tool can also include other land uses and factors that need to be taken into account – thus is can aim to conserve biodiversity, while, for example, maximising goals for carbon storage or avoiding land that is under high-grade agricultural cultivation. The output of Marxan can be imported into GIS software to create maps or for further analysis. Marxan can be freely downloaded from its website.

4.5.3.2 *Zonation*[30]: (Moilanen *et al.* 2005; Appendix A4.4.2) is the other main tool used within for Systematic Conservation Planning. Instead of building up the areas of priority by choosing the most important areas, it iteratively removes the least valuable areas while accounting for connectivity and generalized complementarity. Like Marxan it can incorporate other factors that can be treated positively (e.g. carbon storage) or negatively (e.g. urban area). So, Zonation differs from Marxan in that it doesn't require targets to be set, but identifies the relative priority of areas required to conserve species, taking into account the other factors. The output of Zonation can be imported into GIS software to create maps or for further analysis. Zonation can be freely downloaded from its website.

[28] https://ecosystemsknowledge.net/natural-capital-assessment-gateway (Accessed 8/2/19)
[29] http://marxan.net/ (Accessed 8/2/19)
[30] https://www.syke.fi/en-US/Research__Development/Ecosystem_services/Specialist_work/Zonation_in_Finland/Zonation_software / (Accessed 8/2/19)

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6 Appendices

Appendix 1 The principles for planning a nature network

A1.1 Principle 1: Understand the place

Recognise where the nature network will sit, in terms of how the natural characteristics of the area generate conditions for different habitats and how the cultural landscape character has evolved and is valued. Identify what the area is special for, from a national and local perspective, how nature has changed and the potential for its restoration. This assessment should include biodiversity and ecosystem function, geodiversity, landscape and the historical environment. Understand where people live and work and how ecosystems provide benefits to them. This enables us to identify priorities and opportunities, and to be sympathetic to the current character of the landscape, while not being constrained from accommodating what the future might hold.

Thinking about the landscape context for nature networks means understanding historical change: what has been lost and degraded as well as what still remains; its underlying natural processes, ecosystem functions and services; as well as the location of people and the elements that are valued by them. It is important to bring together geodiversity, landscape character, historical environment, ecology, access, natural capital and ecosystem service information while considering future uses. This will help to identify where there are greatest opportunities to combine ecological restoration with other landscape and ecosystem uses. Public participatory and engagement tools can help in understanding what people value about the landscape and how it might change (see section 1.3 and Principle 2).

To understand more about what makes a landscape distinctive, consider a range of issues including:

- **How geological attributes such as rock, sediment and soil types and their properties influence the landscape** - These all help to define not only the ecosystems that can occur in an area but also the types of landuse that are feasible. No place is a blank canvas and many attributes define the parameters that can be used to deliver network restoration and creation. For example calcareous grassland needs lime-rich soils; soil depth influences what types of plants can grow in an area; and tidal and wave energy will affect sediment types at coastal locations.

- **Assess what aspects of nature are special about the area or have been degraded or become threatened –** There are many sources of national and local data that will show which species and habitats are important in the area. Use these to identify existing and potential core sites for biodiversity as well as opportunities for expansion and joining up existing areas, and improving the wider countryside and urban sites between core sites. It is also important to identify key natural processes, such as water flows and erosion processes within the landscape, as these will play an important part in nature network development.

- **The historical context in terms of ecological changes and the natural ecosystems that have dominated the area in the past** - Many indicators of past ecosystems may still be evident, either in the soil types or landscape character of the place and provide indicators of what habitats to restore. In some cases natural processes will have been controlled or reduced and this will be evident in features such as channelized rivers or streams, with the loss of flood plain functioning, These indicators may also provide information on how difficult ecosystem restoration may be. For example, decades of enrichment of agricultural land will need a longer trajectory for recreation of a more wildlife friendly habitat.

- **The historical context in terms of how people have used the area -** This includes how farming and human habitation has changed over time, what attributes of the social fabric are important and what provision for access to the countryside exists. Historical features might be locally important parts of the landscape that help to define the character of an area (e.g. dry stone walls and hedges), while also being important for wildlife. The location of settlements and infrastructure are important and may constrain some interventions or might offer new possibilities for enhancement.
- **The beneficiaries of the place** - Including local and more distant populations along with society at large, their values and the potential benefits that could be provided to them, while benefiting future generations of people and other species.
- **What trends and scope for future change apply to the location** - For example, sea-level rise will affect coastal landscapes with important consequences for what might be possible in certain areas. Major infrastructure, such as transport systems, can also limit or affect the way a landscape can be developed for nature. Sometimes it is important to acknowledge that current cultural ‘norms’ don’t automatically supersede potential future changes or that preserving the current local landscape isn’t necessarily the best outcome for all of inhabitants (for example, bare hillsides in upland areas may be historically familiar, but may result in downstream flooding events). In such cases, a careful exploration of different interests is required and the trade-offs between different courses of action made clear, so that informed and evidence-based decision-making can be undertaken.

All of these can help set the parameters for what sort of nature network development might be possible and desirable, helping to set priorities.

A1.2 Principle 2: Create a vision

Create a vision for your nature network and be clear about your objectives: specify what the ultimate goals are for the network, to identify the spatial scale, and the environmental and societal aspects that are important.

When designing nature networks it is important, early on, to establish a broader vision for an area. This will aim to create a healthier and more pleasant place in which to live, and one that will be rich in wildlife. A landscape scale vision can set out the intention of how we bring together the landscape, societal and historical context, with ecosystem services and access considerations as part of an overall nature network.

A vision will need to be built through a consensus approach involving a wide range of stakeholders (See principle 2). It should articulate what a landscape would look like in the future, taking into account climate change, and how it will contribute to the needs of society. It will enable engagement with decision makers, local businesses and local people in actively considering the role and importance of the natural environment in the future and how decisions taken today will influence that future. It should take into account the local landscape, geology and history (Principle 3) and try to balance the needs of the various different stakeholders so that the different components will be synergistic as much as possible. However, it will also be important to appreciate that some aspects will be incompatible in places, so it should aim to reduce such conflicts as much as possible.

At its core, will be the need to enhance the environment for wildlife: creating core sites (Principle 4), building resilience (Principle 5), embracing natural dynamism (Principle 6) and encouraging all forms of diversity (Principle 7) – creating more niches for species. All these aspect interact to support each other, but also act to create an attractive landscape that provides a range of ecosystem services to society. The concept of Favourable Conservation Status (see section 3.5.1) provides a good benchmark for helping determine the requirements of species and habitat for an area, to ensure they thrive nationally over the long term.

The value of the vision is that it can help to create a common understanding about what the proposed nature network can achieve, but it can also make clear the area over which it will operate and how it will link with surrounding areas (Principle 8). It provides a basis for understanding the roles of different stakeholders and it can be used to develop a roadmap for how the stakeholders can work together to achieve the short- and long-term aims (Principle 9). It can also provide the basis for establishing the objectives for monitoring and evaluation of a network project so that management can be adaptive as lessons are learned (Principle 10).

A1.3 Principle 3: Involve people

People both benefit from and create nature networks: plans should engage and be created with the community; recognising that the landscapes and ecosystems that support species, also provide **multiple benefits** to people.

People are an integral part of ecosystems within a landscape. They not only shape them but also enjoy the benefits that are derived from them and are affected by any changes within a landscape. A community is more likely to care about, and take action to protect, what they understand. So, it is important to ensure that local people are fully involved in the development of nature networks, not only to gain their support, but also to benefit from their depth of local knowledge.

Listening to the community, ensuring their voice is heard means that they may be more likely to contribute actively to the development and implementation of 'their' plan[31]. According to a literature review undertaken for the *Pathways through Participation* project, 'when an active interest is shown in their opinion...and feel their engagement was influential and acted upon' a citizen will be 'more motivated to be involved and stay involved politically' (Brodie *et al*. 2009). People engage when they think that they may be able to improve the area and their own lives, and tend to disengage when they don't. It should be easier to engage where past investment has already led to improvements in nature and their environment, but may be more difficult when it hasn't.

We therefore believe that nature networks will be made more resilient and sustained in the longer-term by understanding and taking greater account of the social context, the motivations and drivers that affect what people value. Local people help make the landscape and conserve biodiversity, and their actions affect the benefits that others derive from their environment: it is therefore essential to understand local communities and individuals and their social and economic context. Long term relationship building and mutual trust between all parties is the desired goal, to enable local people to have more successful engagement in the future change of their area.

[31] See http://www.participatorymethods.org/

A healthy natural environment will deliver the most effective provision of ecosystem services and so give the greatest overall benefit to society. Well-functioning ecosystems are associated with a wide range of services, such as productive commodities (e.g. food, fibre, energy), security benefits (e.g. flood and erosion control), and social benefits (e.g. health and recreation, spiritual values, noise control, aesthetic value). By restoring ecological processes and structures across our landscapes, not only will biodiversity benefit, but so will the communities that live there. The recognition of these benefits by society will encourage support for the maintenance of these nature networks, providing a mutually beneficial positive feedback loop.

A1.4 Principle 4: Create core sites

Core sites are the heart of nature networks; these are places that sustain thriving wildlife populations that may expand across the network. It will often be best to **build core areas of nature networks by enlarging, connecting and improving existing high quality wildlife sites,** to make well-functioning ecosystems. However, on occasion, it will be appropriate to fill gaps in a network by creating core sites where little wildlife currently remains. Within landscapes, working with **functional ecological units** will provide the building blocks to support abundant and diverse wildlife and ecosystem services.

In many landscapes there will be areas of higher quality conservation land that contain better functioning ecosystems and abundant or diverse wildlife. These represent the core sites around which a nature network will be built. Such sites not only provide the populations of species that will provide colonists for new areas as the network develops, but they will also provide sources of ecosystem services, such as clean water and pollinators, that are important for the people who live and work in the wider landscape. A small number will be Large Nature Areas, of c. 5-12,000 ha in extent, but most core sites will be smaller, being at least 40-100 ha in size (see section 2.4). Without appropriate core sites that are rich in wildlife, it is arguable that much conservation work in the wider landscape will have reduced benefit. Or to put it another way, there's little point making long-distance connections across landscapes if there's nothing to connect!

High quality sites shouldn't be identified simply by 'what they look like': we also need to consider 'how they work'. A site might appear to be 'healthy' while actually be in a state of slow decline because of outside influences such as pollution or isolation. Thus, we need to work with natural processes, as far as possible. We need to plan and manage over a spatial scale that encompasses the extent over which ecosystem processes act, a concept that has been termed '**functional ecological units**' (Jax 2010). This will normally mean thinking at a larger scale than in the past, outside the confines of existing sites, especially where core sites are compromised by activities beyond their boundaries. Examples include: considering the hydrology of the area around a wetland site, or managing 'archipelagos' of sites that together support metapopulations[32] of a particular species.

In most situations, habitats have been reduced in extent, fragmented or only the central parts remain. This has led to a loss of functional integrity and has compromised the ability of sites to cope with external pressures and be resilient to change. This loss of resilience is likely to be progressively more important as climate change develops. If we are to restore ecosystems, we need to understand the degree to which their functions have been degraded. The level of degradation may vary from complete collapse (e.g. when forests have died off or when freshwater is over-enriched with nutrients

[32] A metapopulation occurs in a network of habitat patches containing discrete local populations connected by migration. Some of these populations may go extinct, but then the habitat patch will be recolonised by migrants from other nearby patches. Thus not all the habitat patches will be occupied all the time (Hanski 1998).

(eutrophication)), to varying degrees of degradation, where function is impaired (e.g. certain key species have been lost, soil erosion is severe, or exotic species have invaded), through to intact and fully functioning, with complete food-webs present and sustainable physical processes in operation.

The approach to restoring naturally functioning ecosystems radiating out from the core sites needs to consider a range of realistic possibilities. Understanding the key ecosystem processes of a location, through mapping and working towards a functional boundary of the site, will be an important first step for some core sites in a nature network. While it is important to consider ecosystem function, the extent to which natural processes (particularly hydrological) can be restored is heavily constrained in England. The use of the terms 'natural' or 'naturally' needs to be conditioned, given that England comprises such a man-modified environment, but is important in articulating the need to work with natural processes as far as is possible. The restoration of natural ecosystem function is not a short-term endeavour, but short-term decision-making needs to be compatible with, and work towards, natural ecosystem function if it is to be achieved in the longer term. That being said, we need to be innovative, aspirational and ambitious in our endeavours and be prepared to challenge the status-quo (Mainstone *et al*. 2018).

A1.5 Principle 5: Build resilience

Enhance the resilience of landscapes, ecosystems and their ecosystem services through **restoration that reinstates natural processes,** accommodates desirable change, improves low quality habitat and includes areas that provide buffering from the causes of current and potential future environmental degradation**.** Take opportunities to deliver nature-based solutions to climate change and reduce external pressures (such as diffuse pollution).

The concept of resilience is discussed in detail in section 2.2.4, but, in the context of nature networks, can be summarised as the capacity of a system '*to keep meeting the needs of people and nature in a changing world'*. We are aiming to create landscapes and nature networks that are capable of absorbing, resisting or recovering from disturbances and so maintain a high conservation value over time (Isaac *et al*. 2018). This includes the capacity of nature networks to help improve 'social resilience' – i.e. the ability of groups or communities to cope with external stresses and disturbances as a result of environmental and other changes (Adger 2000).

When considering resilience, one has to first ask 'resilience of what?' and 'resilience to what?' When considering nature networks, some environmental pressures may affect all patches of habitat within a network, but others may affect only specific sites. For example, increased human population pressure may increase disturbance and pollution levels generally, but a housing development adjacent to a protected area will have very specific impacts. Similarly, climate change may result in a general warming over a large area, but a dry period could have very specific effects on the hydrology of a particular wildlife site.

There are some factors that confer resilience to wide range of pressures:

- **Resilient ecosystems are more likely to be complex with high species richness**. This provides some redundancy of functional roles, so that a range of species might be able to perform the same ecological function, should others be lost. For example, should a particular pollinator be affected by a climatic event, then so long as there are other pollinators within the system that can still pollinate the plant(s) in question, this loss is less likely to have a major ecological impact. The diversity of species in a location - or species richness - is affected by factors such as habitat patch area and the physical complexity of the area, as both of these provide more niches for species and increase the levels of interactions between species. For example, an area with both wet and dry patches, provides refuges for wet species in drier years and for dry species in wetter years. Thus, the more ‘natural’ and large a habitat patch is within a network, the more variation is present, and the greater its resilience will be.

- **Buffering wildlife sites can help to improve resilience**, by helping to protect sites from the impact of environmental pressures coming from outside. For example, semi-natural buffer strips around a site can help to reduce the impacts of adverse land management within the surrounding countryside, such as pesticide spray drift and human or pet disturbance.

- **Connectivity between and within habitat patches** (see chapter 2, especially A2.3.2.2) is another key aspect that helps to confer resilience to environmental pressures and change. It can promote the exchange of individuals between habitat patches, ensuring genetic diversity and the repopulation of patches that have lost a species due to some chance or extreme event. Connectivity can take many forms, e.g. physical corridors (structurally connected) or small patches of habitat (‘stepping stones’) that occur between larger patches (functionally connected).

- The promotion of resilience to one pressure can be achieved by **reducing sources of harm or environmental pressure from other sources**. For example, Golden Plover populations breeding in the uplands are stressed by reductions in food supplies as the moorland dries out earlier due to climate change. However, a reduction in predator pressure can act to improve the resilience of the populations to the warming effect, allowing them to persist for considerably longer than if nest predation was an important factor for them (Pearce-Higgins 2011). There are numerous examples of how anthropogenic pressures on an ecosystem can reduce the resilience of system to other pressures, for example phosphorus pollution into biodiverse clear-water lakes, combined with warming or the over-exploitation of predators, can lead to biodiversity-poor turbid water lakes (Folke *et al.* 2004).

- The resilience of ecosystems will be improved **by ensuring that people understand and value the relevance of the environment** in their day-to-day lives, that they recognise the value of greenspace for their health and well-being and if they work towards protecting the aspects of the natural environment that they value.

With enhanced resilience, ecosystems have the potential to provide **nature-based solutions** to societal challenges, taking advantage of the complexity of natural systems and their capacity for self-reorganisation (Eggermont *et al*. 2015). Nature-based solutions[33] use the power of nature to help to reduce the vulnerability of society to environmental risks brought about by climate change and other pressures whilst also being of benefit to biodiversity (Cohen-Shacham *et al*. 2016; Nesshöver *et al*. 2017). Such solutions can be more cost-effective, more efficacious, self-sustaining and longer-lasting than human-engineered solutions (Natural England 2009; Lafortezza *et al.* 2018). They do need to be based on functioning ecosystems of benefit to biodiversity; for example the use of cloned or non-native plants for green roofs would not increase or support local biodiversity and thus shouldn’t be classified as a nature-based solution (Eggermont *et al.* 2015).

Most obvious examples of nature-based solutions are the use of coastal habitats, such as saltmarsh, to reduce the impact of storm surges on valuable farmland and housing (e.g. Dudley *et al*. 2010, Morris *et al.* 2018). In catchments, the use of trees, and of ponds with leaky barriers, can reduce the risk of flooding by attenuating run-off, with the added benefits of reducing diffuse pollution at the same time (e.g. Wilkinson *et al.* 2014). Urban physical and mental illnesses can be relieved by the

[33] When discussing adaptation to climate change impacts, these methods are often called Ecosystem-based Adaptation (Rizvi *et al*. 2015).

provision of green spaces and protected areas for biodiversity (Bragg & Atkins 2016; McKinnon *et al.* 2019).

It is important to note that not all systems will be resilient to all environmental pressures and that some change is likely to be necessary and will happen regardless of our best efforts – in this case we must prepare to accommodate that change (see Principle 6). Providing that the new system is well structured ecologically and functioning effectively, then it may be appropriate to accept such change and work with it, rather than going against the flow. In this case, one is managing for healthy ecosystem function rather than necessarily worrying about which particular species, for example, occupies a site. This is a rather radical concept in UK conservation, but it recognises that sites are part of a network rather than being considered on their own. So long as the network contains the suite of biodiversity that is to be conserved, then their actual locations can be considered as of secondary importance.

A1.6 Principle 6: Embrace dynamism

Remember that in a natural state, **ecosystems and landscapes are inherently dynamic over short and long time scales;** allow natural processes to operate whenever possible, as they will aid restoration of ecosystem function and enhance the sustainability of conservation efforts.

Ecosystems are dynamic. Therefore the development of nature networks and the setting of ecosystem restoration goals should recognise and incorporate this dynamism, instead of trying to recreate what was previously present, or constrain a system so that it remains exactly the same. Change and dynamism is a feature of living systems and so wherever possible, landscape management should allow for hydrological and geomorphological processes to take place. Such dynamism will help develop and maintain the habitat mosaics (mixtures of habitats) that are important for many species. These are the elements that will deliver and help build an increasingly resilient nature network with abundant biodiversity.

Conservation targets for a site might need to be applied in a more flexible way in future. They might need to recognise and allow for change and species movement, whilst still achieving conservation goals at the network level. Although, our first aim is still to help a species to persist in a location for as long as possible, there may come a time when it may not be sustainable. Then our aim should be to facilitate movement and persistence within the wider network. These two aims will be achieved on different timescales, but they both require planning and action at the early stages of network development. The impacts of climate change make such planning particularly important, as changes are already occurring within our ecosystems (Morecroft & Speakman 2015).

Whilst ‘natural dynamics’ should be the aim over the longer term, this may need to be tempered in cases where habitat management (e.g. grazing, mowing, coppicing etc.) is still needed to retain features, especially in less natural systems or on smaller wildlife sites. Examples of the situations where constraints on encouraging natural processes might occur include:

- Multi-functional systems: where nature is found within a human dominated landscape (e.g. urban parks, gardens) with reduced ecological functionality and value.
- Semi-natural systems: e.g. cultural-historical systems: ecosystems that inherently depend on human intervention to maintain early successional stages (chalk grassland, heathland, coppiced woodland, parkland etc.). Where wildlife have found a place and is now dependent on their long association with low input historical land management practices. These systems can be very biodiverse and management focusses on maximising diversity through active intervention and creating the right conditions at small scale. However, some enhancement of natural processes may still be possible in such areas.

The emphasis on dynamism provides a challenge for how people view their landscapes. Society easily adjusts to gradual change, but sudden or large scale changes can be viewed with disquiet. In part, this reflects a tendency for society to lose its connection with nature and the fact that it is inherently dynamic. We must learn to embrace the dynamism of nature, learning to welcome an approach that allows more space for natural processes to occur (see 3.4 for further elaboration). The engagement, change in public perceptions and social learning that is needed around this is as important as the ecological challenges associated with the restoration of natural processes in ecosystems (see Principle 2).

A1.7 Principle 7: Encourage diversity

Nature networks need to include **a diverse physical structure,** influenced by the underlying geodiversity, to accommodate the widest variety of opportunities (niches) for species. Biological **complexity and landscape diversity** are important to facilitate resilience**.** Such diversity is best founded on the restoration of natural environmental processes where this is possible, overlain by vegetation management regimes that encourage further diversity.

In general, a greater variety of physical structures will provide a wider range of microhabitats, niches and microclimates for species. Examples include standing and fallen dead wood, fallen trees in rivers, scrub, and a range of vegetation conditions from patches of open ground to very dense vegetation. This is related to the 'mosaic approach' of habitat management developed by Natural England (Webb *et al*. 2010) that recognises the need for many species to have a suite of different habitat resources throughout annual, seasonal or even daily cycles. Natural processes, such as variable water levels or the impacts of roving herbivores, generate the ecological dynamism that is key to generating the habitat mosaics at all spatial scales. So embracing natural dynamism (Principle 6) is fundamental to the encouragement of diverse physical and biological structures in a network.

Species' habitat requirements also need to be considered at different spatial scales, including both the internal characteristics of wildlife sites and habitat patches, to how those sites and patches are arranged in the landscape. Thus a species might require a diversity of habitat types within a small area during the breeding season, but this might widen out to cover a wider diversity of habitats and patches, over larger areas, during other times of the year. Therefore, a landscape that has a good variety of different types of habitat can often support a greater biodiversity than would be indicated by the number of habitats present. Furthermore, landscape-scale mosaics can also help improve the stability of populations, by ensuring a variety of suitable resources.

Biological complexity and landscape diversity is important. Systems with more complete food webs and species filling a wider range of functional niches will be more resilient to change, so providing greater ecosystem stability in the future. Certain species have a larger impact on their environment than their size or numbers would suggest, often being described as ecosystem engineers (e.g. Boar and Beaver). These 'Keystone Species' can have a role in driving natural processes, modifying the environment, creating habitat and new niches for other species, thereby adjusting the ecology, and can help with the restoration of a degraded system. The impact of these species is starting to be better understood as large scale re-introductions occur, but our understanding is at an early stage (e.g. Beavers, Gaywood 2015). It is clear that better evidence and knowledge on how they may interact with restoration of ecosystems is very important.

A1.8 Principle 8: Think 'networks'

Networks need to be **planned at multiple spatial scales and address multiple issues.** Joined-up actions across adjacent landscapes help to deliver integrated outcomes and ensure that the network acts as a coherent whole for all species (especially for those that live in the wider countryside), ecosystems and people within the area.

For biodiversity, networks need to provide appropriate habitat for each species at the spatial scales needed to support daily, seasonal and inter-generational movement patterns, supporting gene flow between populations and long-distance dispersal. Networks also need to provide habitat for a range of different species, which might vary greatly not just in the resources they require but in the area over which those resources need to be available. Thus, it is important to consider the needs of wider countryside species that use habitats that are outside any core sites for wildlife. Further, as climate change affects the climate suitability for species in a location, they will need to be able to redistribute across the network to maintain population resilience – and network design needs to recognise this.

The smaller-scale components of networks are often a vital foundation for networks over larger areas. It is important that networks are built around core sites of high nature conservation value which are sufficiently large and of sufficiently high quality to support large populations (Principle 4). This will give species the greatest possible chance of persisting if conditions become unsuitable, and provide core sites from which individuals can disperse. Bigger is always better in the long term, with larger patches of habitat being more resilient and adaptable to change. Understanding the large-scale context may help to determine the priorities for individual wildlife sites within an area and how they should be managed – we should plan both ‘up’ from sites to large-scale areas, and ‘down’ from large-scale networks to individual sites.

Within any landscape there are multiple landuses to be considered and balanced to take into account the needs of local communities as well as of society as a whole. There are systematic conservation planning tools (see Chapter 4 for a review) that can help in understanding where these different landuse options might conflict and can also help in determining how compromise solutions can be created that help to meet the majority of each stakeholder’s requirements, while meeting biodiversity targets. These can be used at a variety of spatial scales, from the local to regional and national scale.

The ecosystem services provided by nature networks depend on landscape characteristics, processes and features that exist within the landscape. However, these are perceived by or delivered to people at different spatial scales, as there will be both local and more distant human beneficiaries. For example, the beauty of a landscape will benefit local people and visitors, but the flood control or carbon storage properties of a landscape will provide benefits to people more distantly. Planning of nature networks must take into account these different spatial (and temporal) scales.

Thus, ‘network thinking’ needs to be employed to recognise the linkages between different parts of a nature network and how they support each other at all spatial scales to provide the abundant wildlife and ecosystem services that society requires.

A1.9 Principle 9: Start now but plan long-term

Identify the locations that can deliver a coherent nature network, but prioritise those locations that provide the best opportunities **for action now,** while developing longer term solutions.

Ideally, the design and delivery of nature networks should be approached in a way that promotes a shared vision for a landscape, and allows and encourages all stakeholders to be involved (Principle 1). We hope that this will enable decisions to be made objectively, transparently, effectively and strategically, using a range of tools and techniques to facilitate this.

Identifying key stakeholders (Principle 2) and identifying the local resources, landuses, opportunities and threats to each is an initial first stage (Principle 3). These can then be reviewed and analysed, for example, using systematic conservation planning tools, to help understand how each aspect affects the others and to determine where pinch-points might be, where synergies occur and where compromise might be achievable.

One of the most powerful aspects of sustainability is that it is inherently forward-looking, providing conservationists with broad principles from which to consider the future of their community or landscape. Approaches to build transformative change should not simply be responsive to current environmental crises but look ahead to the future and travel beyond the boundaries of our current institutions and ways of working. A key starting point will be to look for locations that will deliver integrated outcomes to the greatest possible number of objectives. But these ideal locations may not be the places that provide opportunities for immediate action, so one might have to plan over a range of timescales, whereby different pieces of the jigsaw are gradually built up as opportunities arise.

Strategic planning means taking account of the best contribution a place can make towards network objectives. An understanding of what potential an area has for developing different types of ecosystem and 'how much is enough' at the network scale is an essential ingredient to inform local decisions on shared outcomes. We need to be clear what our overall conservation goals are and the flexibility we have. This means considering where efforts for further improvement are best targeted so that efforts to improve ecological conditions will provide the biggest additional contribution. Being strategic also means avoiding short term actions that undermine or constrain the potential for bigger long term gains.

Finally, in the implementation of a nature network strategy in a place, one should exercise a certain amount of flexibility in the ways that the above principles are applied – not all of them will be applicable everywhere - but they should provide a sound basis for almost any landscape. Nothing is static for long; 'reviewing and revisiting' as priorities change is important. Thus, monitoring of outcomes and the development of network metrics is vital to assess the success of conservation actions to develop nature networks (Principle 10). These will allow the adaptive management of plans over time to fine-tune and optimise conservation action. This will also allow incorporation of how communities' values and conservation knowledge will change and develop over time with new objectives likely to be identified for conservation networks in future.

A1.10 Principle 10: Monitor progress

Evaluate actions and **adapt management** in the light of results, to achieve long-term aims at local and national scales.

It is important to put in place a system of monitoring and evaluation of the progress and success of the development of a nature network, and sufficient resources in the long-term to undertake this. Isaac *et al.* (2018) discuss monitoring and evaluation in the context of an adaptive management framework:

1. Assess resilience using measurable network features – develop network metrics, such as the distribution of available habitat patches to estimate capacity of the network to support key indicator species.

2. Identify plausible actions to improve resilience – usually undertaken at site or habitat patch level, but effectiveness will need to be measured at the species level or across all sites.

3. Evaluate proposed actions in terms of potential gains in network resilience – use modelling and scenarios

4. The best actions identifies in (3) should be implemented and monitored, with a view to using the results to improve future management.

It is worth distinguishing between surveillance and monitoring – the former being repeated surveys using standardised methods, whilst the latter includes a clear understanding of the objectives of the programme and an assessment against a baseline (Greenwood *et al*. 1994). The monitoring and evaluation framework developed to review the progress of the Government's Nature Improvement Areas[34] provides a good model for how this might be implemented to assess nature network development (Collingwood Environmental Planning 2015). This is based on guidance provided in the Magenta Book (HM Treasury 2011), and distinguishes:

- Inputs – such as the resources being invested, such as finance, time, people;
- processes & activities – such as area of habitat created, length of footpaths prepared;
- outputs – the immediate results achieved;
- outcomes – the short-medium term results (say 1-3 years); and
- impacts - longer-term results achieved after 3+ years.

There are a wide range of methods available for monitoring the various different aspects of nature networks. For biodiversity, there are many well researched and validated methods that are used by long-term monitoring programmes, and their use would have the benefit of permitting comparison with other locations monitored by such programmes (e.g. those methods that form the basis of the UK Biodiversity Indicators – Defra 2017). The Long Term Monitoring Programme also uses a suite of methods for monitoring air quality, vegetation, soils and biodiversity which may also provide useful benchmark standards for nature network development (Nisbet *et al*. 2017). The Monitor of Engagement with the Natural Environment (MENE) surveys provide a set of methods and measures that could be useful for monitoring stakeholder engagement during nature network development (Natural England 2019).

A number of tools are available to help guide network project planners through the monitoring and evaluation process. One such is PRISM, specifically designed to help conservation practitioners with the practical approaches and methods that can be used to evaluate the outcomes and impacts of small/medium-sized conservation projects (Dickson *et al.* 2017). Overall, PRISM is useful because it aims to help practitioners go beyond just measuring actions & outputs, but to begin to evaluate outcomes and impacts. It also aims to promote learning, while still remaining within the capacity and resource limits of the project team.

When undertaking new conservation initiatives or trialling new methods, it is important that such interventions are published. This allows the lessons learned to be shared and to inform conservation practice more widely. Currently many interventions are undertaken by conservation practitioners, but we lose the opportunity to learn from these because they are often not properly designed, monitored or written up in an accessible form for others to learn from. Furthermore, there are opportunities for similar actions on multiple wildlife sites to be coordinated, so that the evidence base is greater and the lessons learned more robust. The development of www.conservationevidence.com (accessed 20/1/20) provides a ready-made framework for reporting and disseminating results from small conservation interventions. Examples of how such, often small-scale, studies can contribute to provide a bigger picture is exemplified by the publication *What Works in Conservation* (Sutherland *et al*. 2018).

The value of monitoring and evaluation is that it allows adaptive management to be an integrated part of the development of a nature network. Adaptive management uses the systematic acquisition and

[34] Large discrete areas, where a local partnership developed a shared vision for their natural environment and the development of resilient nature networks at a landscape scale

application of reliable information to improve management over time. Thus, this isn't simply a willingness to change or to undertake flexible management, but is a more rigorous approach based on defining objectives and monitoring progress to achieve those objectives (Wilhere 2002). Ideally this is done with an experimental approach, although it may not always be practical to undertake multiple management interventions for comparison, but it does help to deal with uncertainty of outcomes by providing a structured improvement of knowledge: it is effectively a way of 'learning by doing', but with a scientific approach (Allen *et al.* 2011; Keith *et al.* 2011).

Appendix 2 A detailed review of the ecological requirements of nature networks

A2.1 Networks need to support persistence and movement of species

Ecological theory suggests that in order to maintain a species, a **population needs to comprise c. 5000 individuals** (Traill *et al.* 2007, 2010), but this may be reduced for large-bodied animal species (>1 kg) towards just 500 individuals (Hilbers *et al.* 2017). About **500 individuals are needed to maintain long-term genetic variability and a minimum of 50 individuals to avoid short-term problems associated with inbreeding** (Traill *et al.* 2010, Jamieson & Allendorf 2012). While, for the most part, conservationists will not be sure about the absolute size or the connectivity of the population(s) they are dealing with, these figures are rules of thumb that give some indication of the requirements needed to ensure the viability of the populations of interest. If population size is substantially lower than these figures, then urgent action is needed to bolster numbers and the creation of nature networks to help link up populations are an important part of this conservation work.

Consideration of the **life cycle of an individual** is critical, not only their daily routines but also seasonal movements and migration. Where information is lacking, consideration of the ecology of similar species is helpful. Then, at a bigger scale, one needs to consider population maintenance (through metapopulation dynamics); the need for gene flows, and the response of species to climate change in terms of dispersing across the landscape and resilience to extreme events (see Table A2.1 below).

Nature networks for species therefore need to be considered at multiple biological, spatial and temporal scales, particularly in the context of climate change. We need:

i) to create more habitat to **join habitat fragments** so creating larger sites that support larger populations; and

ii) to **restore connections** between sites and habitat patches to increase movements between sites and species interactions (to aid gene flow among subpopulations and increase the chances of recolonization if the population in any patch is reduced as the result of random or extreme events); and

iii) to **enable longer-distance movement** by species to facilitate range shifts as climatic conditions change, as well as migration.

The first two of these scales ('sites' and 'landscapes') are a vital foundation for the third – it is important that **networks are built around core sites of high nature conservation value** which are sufficiently large and of sufficiently high quality to support large, self-sustaining populations. This will give species the greatest possible chance of persisting if conditions become unsuitable, and provide core sites from which individuals can disperse. Such sites will also need robust ecosystem processes to help ensure the continued provision of ecosystem services. They are the building blocks of a resilient nature network but the majority of our designated sites do not currently meet these criteria, often because they are simply too small (Shwartz *et al.* 2017) – such sites will need to be managed intensively until they can be brought into a more robust network.

Without appropriate core sites, it is likely that much conservation work in the wider landscape will be ineffective. Or to put it another way, there's little point making long-distance connections across landscapes if there's nothing to connect. The types of connections are also important (see Table A2.1). However, understanding the large-scale context may help to determine the priority of individual wildlife sites within an area – we should plan both 'up' from wildlife sites to large-scale areas, and 'down' from large-scale areas to the sites within them.

Table A2.1 Nature networks to support the persistence and movement of species

The daily routine of an animal	Moving around a relatively small area – perhaps going to a number of different patches of habitat – crossing any gaps to do so – the need to find food (which may be from different sources in different seasons), a sleeping place, a breeding place, a roosting place.
The seasonal routine of animals	Widening out of the breeding season area as resources become more scarce seasonally; moving more widely to find new sources of food; moving to find localised breeding places (e.g. ponds); moving downhill to avoid deteriorating conditions on hill tops in winter; etc.
The annual cycle of an organism	Dispersal of young to new areas for breeding, growing, long-distance migration – requiring (for animals) fattening areas, stopping off points, and non-breeding areas and (for plants) animal vectors for seed dispersal and suitable soil and growing conditions.
Metapopulation dynamics and genetic mixing	Populations need to be able to exchange individuals to ensure population persistence on each habitat patch (metapopulations) and ensure genetic diversity – this can happen over a range of spatial scales, but are facilitated by nature network features, some of which might be very small scale but potentially absent from the landscape today because they've been removed in the (relatively recent) past e.g. ponds, hedges, and dead and decaying wood in individual veteran trees and in orchards/parks.
The factors affecting dispersal	Dispersal is the movement of an individual from its location of origin to where it will attempt to breed (natal dispersal) or between breeding sites (adult dispersal). Some plants and animals have very low dispersal capabilities, but others are able to disperse long distances either by their own agency or by being carried in a passive way by wind, water or animal. The numbers of dispersers and the success of dispersal depends on a number of factors (Clobert *et al*. 2009) – some of which are external to the organism, some are internal and others evolutionary, for example: ▪ Factors on the source sites – habitat quality and availability; competition for resources; inbreeding avoidance; excessive propagule[35] production; body condition; sex (males or females may disperse more) ▪ Factors on transient sites – sufficient resources and conditions for refuelling, shelter, safety from predators ▪ Factors on receptor sites – sufficient, appropriate, and reliable resources; low competition; low predation or disease risk.

[35] Propagule is here taken to mean the offspring of animals or any structure that can give rise to a new plant or fungus, mainly seeds or spores in this context.

Rare long-distance dispersal events are important	Even though they are difficult to study or predict (Nathan 2006; Nowicki *et al.* 2014), to be successful such events still depend on the presence of good quality receptor sites and probably depend on source sites with sufficient production of potential colonists.
Contrast between mobile and immobile organisms	Species that don't actively move need to have sufficient propagules travelling far enough to find a suitable living space for the next generation. Thus, for immobile organisms, 'stepping stones' between source and receptor sites need to provide all requirements. This contrasts with more mobile species, which just need somewhere to fatten up or even rest. Thus a network for immobile species must comprise patches of habitat that meet the minimum suitability criteria for the species to survive and reproduce – the concept of stepping stones for relatively immobile species may be quite different compared to those for mobile ones that can use such sites for just 'passing through'. For example, some saproxylic species depend on dead and decaying wood in the right condition in close proximity to existing wood decay to have breeding success. They will need veteran trees in the landscape, whether they be in woodlands, orchards, parks or present as individual trees e.g. in hedges/fields etc.

A2.2 Variation in species requirements

Each species has its own unique **ecological niche** (Box A2.2) and thus different requirements. Furthermore, they may 'see' the landscape in very different ways – what can be barriers for one species could be essential habitat for another. To take an example, a Corn Bunting and a Willow Tit living in the same landscape. For the former, the farmland is the habitat and the woodland relatively unusable 'matrix', and for the latter, the reverse is true.

An additional problem arises because the way humans see a landscape might be quite different from how a species experiences or perceives it – and quite possibly this has consequences for the conservation of the species. It means that a certain level of fragmentation in a landscape, as perceived by humans, will be more (or less) serious for some species than others (or conversely, that a particular network of wildlife sites will be better for some species than others) (Manning *et al.* 2004). Maps of land cover may not always be a good approximation of the potentially suitable habitat that actually exists for a species. As an example, mature trees within the landscape may all look similar to the human eye, but we cannot tell what is going on within them. Those with extensive columns of heart rot (which do not harm the tree) will be very attractive to various insects who can detect this rot from a great distance.

Box A2.2 - Ecological niches explained.

The habitat of an organism is 'the place where it lives', whereas the ecological niche is the range of conditions within which the organism can survive.

A species' resource requirements, such as light, nutrients, food, breeding resources etc., can be split into biotic (biological interactions) and abiotic (environmental interactions) variables. Such factors may include the organism's life cycle, habitat, trophic position (place in the food chain), and geographic range.

In a simple graph you could plot one of these variables against another variable to show the upper and lower limits of what is required or is usable by a species. In practice each species does not have just two constraints but many, but, for illustrative purposes, let's just stick to two (see Fig. A2.2).

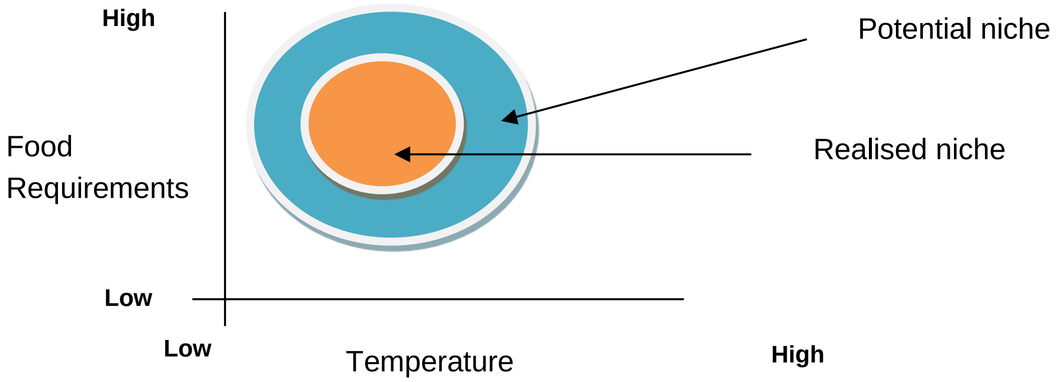

Figure A2.2: N- Dimensional Fried Egg Model

Niches can be divided into the **potential niche**; the full range of conditions (abiotic and biotic) within which an organism could survive in the absence of impacts from other organisms. In some cases the potential niche is not clear because of historical factors that limit current distributions; for example red kites were apparently limited in niche to the Welsh uplands but had been limited there due to historical persecution, and reintroductions in England and Scotland have shown that it has a much wider potential niche (Wotton *et al*. 2002).

Thus the **realised niche** is the actual range of conditions within which the organism currently occurs, due to being forced out of other potentially suitable niche 'spaces' by competition from better suited organisms, predation or disease. It is rare for two species to occupy the same niche in the same environment for long unless they are limited by other factors.

Some plants and animals, are specialists, having a very narrow niche and need specific habitat conditions and surroundings to survive (e.g. dog's mercury *Mercurialis perennis* and herb-paris *Paris quadrifolia* in established woodland). Other plants and animals are generalists, with a broad niche and can survive in a wider range of conditions, e.g. the white clover *Trifolium repens* or stinging nettle *Urtica dioica*.

A2.3 Wildlife site[36] and landscape influences on network design and rules of thumb

The *Making Space for Nature* report (Lawton *et al*. 2010) identified very clearly that 'coherent and resilient ecological networks' required the pursuit of the four general principles of 'more, bigger, better and joined'. Following Lawton *et al.* we have split 'joined' into two, as evidence and theory suggests that the hierarchy of importance should be:

Better site quality	**>**	**Bigger sites**	**>**	**More sites**	**>**	**Stepping stones & permeable matrix**	**>**	**Corridors**

The order of the last three will vary according to the species being considered and the landscape that is under consideration (e.g. the relative cover of semi-natural habitats), but as a general rule this hierarchy is sound (but see Box 2.4).

These can be broken down further into a series of network attributes at site or habitat patch and landscape levels and we can identify some rules of thumb to help guide our thinking (listed in Tbale 2.4). **It is important to note that the rules of thumb work best at the level of communities or for species with shared characteristics**. When considering individual species, which have individual requirements, the rules of thumb are only reflecting the best approach as an average. **So caution is needed for individual species whose characteristics may differ substantially from that average.** Whilst basing decisions on species-specific evidence is the best route, the use of rules of thumb can be effective (Skirvin *et al.* 2013) and should be followed in the absence of more detailed information. They can also be used as the basis for further scientific testing so that they are refined. Ideally all conservation interventions should be implemented in a way that allows their efficacy to be evaluated and we would strongly encourage users of this guide to do so, and contribute such evaluations to the wider scientific literature, such as through www.conservationevidence.com (accessed 20/1/20)

A2.3.1 - Attributes at the scale of wildlife sites

A2.3.1.1 *Improving core habitat sites ('better')*: Lawton *et al.* (2010) write about 'better' in terms of better habitat management and improving heterogeneity. They concentrated on the need to improve the condition of protected or designated wildlife sites, many of which are categorised as 'Unfavourable' because they are not meeting their conservation objectives. The problems can be due to inappropriate management on the site (e.g. inappropriate burning) or outside the site within the network (e.g. water pollution). There are also a number of more general within-site principles that should be considered if the aim is to create and enhance wildlife sites so that they are more resilient to shocks and pressures in the future. These can be summed up as

'*Big Enough, Messy, Complex and Dynamic*'.

[36] 'Sites' do not necessarily mean designated sites for conservation, but can include any patches of habitat for wildlife

Big Enough – While there are various aspects of as site for wildlife that are to do with size, *per se*, which are discussed below (2.3.1.3), the concept of being 'big enough' is more to do with quality, although the two are very closely linked. The aspiration should be to work at a larger ecosystem scale to provide sites of sufficient size such that they cover '**functional ecological units'** (Jax, 2006) – sites that encompass the space over which particular natural processes (functions) act. This will often mean thinking at a larger scale, extending or buffering existing site boundaries – for example, to consider the hydrology in the area around a wetland site. Sites that are 'big enough' will also be sufficiently big to improve quality by providing space for natural processes to occur (see 'messy' and 'dynamic' below).

Messy - Conservation sites need a diverse internal physical structure to provide a wide range of microhabitats and microclimates for species. Often these structural elements are seen as 'messy': things that have been removed from many landscapes – such as standing and fallen dead wood, fallen trees in rivers, scrub, patches of bare ground and very dense vegetation (such as dense bramble patches), and at a larger scale, areas for rivers to meander and overflow in the landscape. This relates to the '**mosaic approach**' of habitat management for species, encouraged by Natural England, which recognises the needs for many species to have a suite of different habitat resources throughout annual or even daily cycles (Webb *et al.* 2010). For example, a digger wasp may forage for its caterpillar prey amongst heather, but then bury these, for their young to feed on, in bare patches of sandy soil some distance away; moths of calcareous grassland are more abundant where there is occasional woody vegetation, such as hedgerow trees, to provide shelter (Alison *et al.* 2017). The creation of messiness often requires **ecological disturbance** - events that disrupt the ecosystem, to bring about a change (White & Pickett 1985) that maintains species composition and diversity (Mori 2011). In conservation practice the use of large grazing animals as **ecosystem engineers** (Jones *et al.* 1994, Manning *et al.* 2015) is often used to manage habitats but also helps to create disturbance features. Pigs or wild boar *Sus scrofa* are major ecosystem engineers in this way – creating wallow pits and digging up the soil to access tubers (Sandom *et al.* 2013) and can be important seed-dispersers (Schmidt *et al*. 2004), although they can have detrimental impacts on some species (Barrios-Garcia & Ballari 2012).

Complex – this refers to biological complexity: systems with more complete food webs and species filling a wider range of functional niches (see Box A2.2 above) are more resilient to change. Increased biodiversity can provide an 'insurance' or a buffer, against environmental fluctuations, because different species respond differently to these fluctuations often helping to maintain the stability of ecosystem processes (Loreau *et al.* 2001; McCann 2000; Moughi & Kondoh 2012). Research suggests that the addition of missing elements of food webs can create opportunities for other species – these are not just examples of trophic cascades (the ripple effect down a food web from the addition or subtraction of top predators) but can occur across food webs through changes in competitive and consumption interactions (Säterberg *et al.* 2013). To increase the biological complexity of an area, conservation actions might include the restoration or creation of niches for species, so allowing natural colonisation. In some cases the reintroduction of species may be required where they are unlikely to colonise naturally within a reasonable timescale (Carter & Newbery 2004).

Related to the issue of biological complexity is that of biological homogenization – the replacement of local, specialist, species by other, more widespread, generalist species (Clavel *et al*. 2011). This is often associated with the loss of ecosystem functioning, with a consequent deterioration of ecosystem goods and services. **Rare species** can have surprisingly important impacts on ecosystem interactions (Leitao *et al*. 2016), so are important for conservation – for example rare species in grassland habitats are associated with high levels of ecosystem multi-functionality, possibly because they tend to have unique roles within the ecosystems (Soliveres *et al.* 2016).

Dynamic - We need to remember that ecosystems and landscapes are often inherently 'fluid' and dynamic (Manning 2009). Dynamic river courses and coastlines that continuously create ephemeral habitat, providing a range of additional habitat resources for species are important examples of dynamism. This is something that has sometimes been lost in conservation approaches, especially in some strong cultural landscapes. Furthermore, dynamism will be impossible to ignore as climate change continues to affect the natural environment (see Box 3.5.2). We will need to apply concepts such as 'favourable condition' and management for particular vegetation classifications (e.g. the National Vegetation Classification of Rodwell, 1991-2000) in a more ecologically appropriate way in future, working with nature not against it. Thus it might not be appropriate to resist ecological succession or changes in community structure occurring as a result of climate change.

Finally, there is already a large amount of evidence that recent warming has affected species persistence (Suggitt *et al.* 2014) and distributions (Hickling *et al.* 2006, Morecroft & Speakman 2015). Future scenarios show that large areas of the country might be subject to climates that we do not experience at present (Hossell *et al.* 2005), suggesting that ecological communities and species interactions could be altered in unpredictable ways. A more dynamic, heterogeneous and functionally connected natural environment is likely to help species adapt to a changing climate, providing conditions and microclimates that will promote persistence of current species and colonisation of new ones, facilitate range shifts and help to maintain conservation interest across a landscape even if the features on individual sites change (Thomas *et al.* 2012, Johnston *et al.* 2013, Gillingham *et al.* 2015).

A2.3.1.2 *Other aspects of wildlife site design*: There are other aspects to the design of wildlife sites that can affect their 'quality':

Edge effects can be influential – affecting species positively or negatively depending on their ecology (Murcia 1995). Habitat specialists that are restricted to one type of ecosystem tend to be affected detrimentally by 'hard' edges which make a strong delineation between habitats (e.g. Fletcher 2005; Lacasella *et al.* 2015) – this may be because the microclimate at the edge of habitats may differ, resulting in different growing conditions for plants and different vegetation types for animals (e.g. Baldi 1999; Wright *et al.* 2010, Riutta *et al.* 2014). Herbivory or predation may occur at higher rates on edge habitats because they allow species from adjoining habitats to use the space (Winter *et al*. 2000). Influences from the surrounding land are also important (Rand *et al*. 2006), for example disturbance (Finney *et al.* 2005), pesticide drift (Marrs *et al.* 1989) and nutrient enrichment (Bowie *et al.* 2016) – in heathlands, the eutrophication effect of fertilizers used on arable fields can penetrate for 8m from the edge (Piessens *et al.* 2006), while the impacts of nitrogen oxides from car pollution can reach as far as 200m (Spellerberg 1998). In woodlands, agrochemical effects from adjacent farmland are only detected within the first 12m of the edge (Gove *et al.* 2004), but changes in microclimate can penetrate between 50-100m into woodland and specialist woodland moth populations maximise at 200m from an edge (Peterken 2002, Riutta *et al*., 2014). Edge effects differ depending on the habitats and are often asymmetric, for example Boetzl *et al.* (2016) demonstrated that the penetration of forest species into adjacent grassland was far greater than the penetration of grassland species into the woodland. Edge effects appear to be non-linear – being most pronounced in the first 10-20m (Riutta *et al.* 2014) Thus, long, thin patches with a relatively high edge to area ratio are likely to be of lower quality for habitat specialists than one that is more compact. Extinction rates in long thin patches have been shown to be twice as high as in more compact habitat patches (Skirvin *et al*. 2013) and their butterfly populations are less resilient to increasing drought with climate change (Oliver *et al*. 2015).

However, **ecotones** can be beneficial. These are where two or more types of habitat blend more gradually into each other, often along an environmental gradient (e.g. a change in wetness towards a lake), or gradients between habitats for example scrub and tall herb vegetation between woodland and open habitats such as grassland (e.g. Kollman & Poschlod 1977). Many, often more generalist species thrive in these intersections of habitats, and where there is a range of adjacent habitats to utilise (e.g. Bieringer *et al.* 2013; Calladine *et al*. 2013).

Buffers - Buffer areas of reduced intensity of land management around core sites (Lovell & Sullivan 2006) can help to reduce the negative impacts of the edge effects and promote the potential benefits of ecotones. These zones can help to reduce the impacts of adverse land management within the surrounding countryside, such as pesticide spray drift and human or pet disturbance, and are intrinsic to the design of UNESCO Biosphere Reserves (Ishwaran *et al.* 2008). For example, a study of the ranging behaviour of urban domestic cats, suggests that a buffer zone of 300-400m would be required to protect a site from their predation impacts (Thomas *et al*. 2014). Buffer zones can provide qualitatively better habitat than the surrounding countryside, allowing species to thrive and thus bolster populations inside the core sites. A 50m buffer strip can be valuable for amphibians and reptiles (Semlitsch & Bodie 2003). Buffer zones of 500m around *Natura 2000* sites in Europe hold more red list plants than outside these zones (van der Sluis *et al*. 2016). Buffer zones can also reduce the impact of edge effects by providing a softer transition between the core site and the surrounding countryside (Fischer *et al.* 2006). Agri-environment measures often promote the use of grassland buffer strips along water-courses to reduce the rate of nutrient run-off. This is important for the water quality of freshwater conservation sites alongside the fields or downstream, and benefit wildlife populations there (McCraken *et al.* 2015; Noij *et al*. 2012). The size of a potential buffer strip may vary according to the size of the core site and the nature of the threats that might affect it from the surrounding landscape. Thus the extent of buffering will need to be undertaken pragmatically and should be reviewed in the light of the impacts observed in the core site. Although the evidence on the size of buffer strips is limited, the information above on the penetration of edge effects into habitats, suggests that buffer areas around biodiversity sites should be at least 50m wide, preferably more than 100m wide, and may need to be up to 500m wide.

***A2.3.1.3 Increasing the size of core habitat sites ('bigger')*:** Increasing the size of wildlife sites is closely related to making them better, because they need to be 'big enough' to encompass functioning ecological units (Jax, 2006; Moss 2008) and to support sufficient dynamism to allow a mosaic of different successional stages to co-exist, potentially as a shifting mosaic throughout a site (Turner *et al*. 1993; Mori 2011). However, larger areas are also able to support bigger populations of species, which are thus less subject to the random chance of extinction due, say, to a run of poor years for reproduction, i.e. species will be more resilient to environmental shocks and pressures (Verboom *et al*. 2010; Oliver *et al.* 2013, 2015). Increasing the size of a site can also help to reduce the progressive loss of species that occurs with habitat fragmentation and reduction, due to the 'extinction debt' involved (Tilman *et al.* 1994).

Larger wildlife sites will tend to have a wider range of habitats that will provide more opportunities for different species, increasing species diversity as well as providing a wider range of resources for individual species – again, conferring resilience should an important resource become depleted temporarily (Roxburgh *et* al. 2004; Bennett *et al*. 2006). Bigger wildlife sites are also more likely to be 'self-sufficient' in terms of ecosystem functioning, with less reliance on nutrient inputs from outside (Moss 2008). They may contain larger bodied keystone species that act as ecosystem engineers that help to maintain or increase the range of niches available, prevent dominance by one species and create opportunities for a greater complexity of food webs (Jones *et al.* 1994, Navarro *et al*. 2015,). Disturbance, along with space to allow natural processes to occur, is far easier to accommodate on larger sites. All of these help to improve the resilience of ecosystems to external pressures.

Which of your wildlife sites should you increase? – Following on from the logic that sites needs to be big enough to facilitate natural processes within functional ecological units, the priority for site enlargement must be those sites for which critical ecosystem processes *outside* the site are not managed sympathetically for conservation *within* that site. For example: wetland sites most urgently needing increases in size will be those that do not include critical elements of the hydrological system. Thus, basin mire sites should ideally include the basin slopes; raised bogs should include the whole peat bodies; and valley mires need the protection of valley slopes and adjacent water courses. Similarly, increasing site size can be the best answer to dealing with specific threats, such as edge effects and the risk of local population extinctions.

Restoration of degraded habitat surrounding existing sites is important. Understanding what has been recently lost or has reduced in quality, but still has the potential to be restored as priority habitat and to support the functioning of core sites, can be valuable for helping to target habitat restoration as part of the development of nature networks. The landscape setting, geology, geomorphology and soils all help determine which areas have good *Habitat Potential*[37] for restoration opportunities.

To make the most of the resources and gain management efficiency savings and to improve the network maximally, it is often best to **join one or more existing fragments** together. Metapopulation dynamics provides some rules of thumb for this, all other things being equal (Etienne 2004):

- If the aim is to improve connectivity by decreasing the distance between two patches, by increasing the size of one of those patches, then **choose the two largest patches** in the landscape to improve metapopulation persistence.
- If there is an opportunity to buy a **fixed amount** of area to add to one of your sites, then **choose the smallest site**, (bearing in mind whether the new site will be sufficiently big to be viable in the long term (see below).

How big should a wildlife site be? There is relatively little information available on this, with respect to species persistence, except for woodland. This is summarised in Table A2.3.1.3.

Table A2.3.1.3 How big should a wildlife site be? Studies that have suggested minimum areas to support populations of different taxa in woodland habitats.

- Herbaceous species: require > 1.5 ha and preferably > 5 ha to support typical woodland species (Usher *et al.* 1992); species richness increases to 40 ha (Humphrey *et al*. 2013)
- Bryophytes: require > 3.5 ha to support a diverse array of bryophyte functional groups (Humphrey *et al.* 2013)
- Saproxylic Beetles: with low dispersal abilities require > 100 ha (Humphrey *et al.* 2013)
- Birds: the species richness of woodland birds is maximised at > 10 ha (Bennett & Saunders 2010), but Marsh Tit *Poecile palustris* requires >25 ha and Great Spotted woodpecker *Dendrocopos major* > 100 ha (Peterken 2002)
    - if < 1.5 ha, some woodland bird species will not breed (Hinsley *et al.* 1995)
- Mammals: the likelihood of dormice occupying a suitable woodland is maximised if the woodland is > 20 ha (Bright *et al.* 1994; Bennett & Saunders 2010)
    - Red squirrels *Sciurus vulgaris* require > 10 ha (Peterken 2002)
- General: > 3 ha is required to provide some internal habitat heterogeneity, but >25 ha is required if the rides are to be open enough for open-habitat species (Peterken 2002).

[37] A GIS data layer created to facilitate the delivery of 'Outcome 1D' of the *Biodiversity 2020* strategy (Defra 2011), is available that identifies Habitat Potential within England. Outcome 1D aimed to restore at least 15% of degraded ecosystems as a contribution to climate change mitigation and adaptation. The data layer is based on knowledge of the historical distribution of habitats and the suitability of underlying soils; see Morgan *et al.* (2014).

In conclusion, for woodland, we would suggest the following rules of thumb. Although we recognise that the evidence base is relatively thin, we have applied the precautionary principle in developing the rules of thumb, so that they are generous and are likely to be ‘no-regrets' suggestions. While some species may be able to persist in smaller patch sizes, evidence is lacking as to which species this may apply to.

- **To maximise the species richness of lower and higher plants and woodland vertebrates, with some heterogeneous structuring, a wildlife site needs to be at least 40 ha.**
- **To support populations of wider-ranging species or those with specialist requirements and low dispersal abilities, a wildlife site needs to be at least 100 ha.**

In addition, for heathland, De Vries (1994) and Webb & Thomas (1994) defined the minimum area of lowland heathland, that is functionally viable for its characteristic species (invertebrates in those studies), as around 30 ha. Below that size, species tend to go extinct, particularly those with lower powers of dispersal. Below this threshold, generalist species from hedge habitats will invade the small fragments (Webb & Hopkins 1984).

For breeding bitterns there is evidence that reedbeds of at least 20 ha in extent are preferred (UK Biodiversity Steering Group 1995).

The importance of patch size can be affected by the permeability of the surrounding matrix and the mobility of the species. It is predicted that the relationship would be strongest for specialists with poor mobility, and in landscapes where the matrix is largely impermeable or for species where the matrix does not provide secondary habitat or resources. This is borne out by empirical studies that have shown stronger area relationships for specialists and species with poor mobility (Marini *et al.* 2010, van Noordwijk *et al.* 2015), but less apparent or non-existent relationships for generalist species or in areas with greater connectivity (Gavish *et al.* 2012, Rosch *et al.* 2013) or matrix heterogeneity (Hatfield & LeBuhn 2007, Öckinger *et al*. 2012). In addition, the impact of area may also be influenced or masked by other patch attributes such as floristic richness and habitat heterogeneity (Báldi 2008, Marini *et al.* 2010, Pöyry *et al.* 2009, Slancarova *et al*. 2014, Woodcock *et al.* 2012), all of which influence the quality of patches.

In the absence of much data from other habitats, it is suggested that the guidelines for woodland be applied cautiously as minimum requirements more generally. However, these should be put in the context of the requirements for functioning ecological units and the hydrology of areas such as upland moorland often require substantially greater areas to be conserved.

A2.3.2 Landscape-scale attributes

A2.3.2.1 *Increasing the number of core sites ('more')*: There are two aspects to increasing the number of core sites in a network: first there is the need to actively create and restore more patches of habitat as part of the network; and second, there are currently unprotected sites that are potentially important components of a network that could easily be lost if not given better protection, with disproportionate impacts on network coherence..

<u>Habitat creation</u>: The amount of land in which conservation is a major or the only consideration for its management is relatively small in England. Designated National Nature Reserves and Sites of

Special Scientific Interest[38] only account for 6.4% of England's land surface, (compared to 14% in Germany & Italy; 17% in France and 34% in Spain[39]) and if one includes a number of large-scale (>10 km^2) conservation initiatives that are managed by one or a few organisations or individuals, such as the Great Fen Project, Wild Ennerdale and Wicken Fen Vision, this figure rises to 7.4% (Shwartz *et al.* 2017). In addition, these protected areas tend to be concentrated in upland or low quality agricultural land, so some areas of the country have few protected sites for conservation. To support viable and sustainable populations of biodiversity, there is not only the need to improve the quality of existing protected areas, and to increase their size, but we also need more completely new sites. Examples of where new sites have been created include Lakenheath Fen in Norfolk, which is a large wetland reserve created on arable land (Sills & Hirons 2011), and the creation or restoration of semi-natural habitat in quarries such as the Nature After Minerals programme (Davies 2006; http://afterminerals.com).

Such new sites will perform a number of important functions. They will provide new habitat for species, boosting their populations and improving connectivity between existing sites. These will help to reduce isolation and enable the interchange of colonists between sites, as well as the longer-term and longer-distance movements that may arise as a result of climate change.

Areas with high topographic heterogeneity are also potentially valuable when considering where to locate new sites. Increased topographic heterogeneity increases the range of niche space (Field *et al.* 2009) and provides opportunities to allow populations to adapt to climate change (Maclean *et al*. 2017). Climate change is shifting the areas of suitable climate to the north and to higher altitudes for many breeding species, as temperatures rise (Morecroft & Speakman 2015; see Box 3.5.2). Wintering waterbirds have shifted their distributions to the east as winters have become milder (Austin & Rehfisch 2005). However, there are locations that show less climate change than surrounding areas – essentially providing '**refugia**' in which species can persist (Ashcroft 2010; Dobrowski 2011). Areas which are more steeply hilly, with north-facing slopes and with taller vegetation cover (De Frenne *et* al. 2013) are likely to provide these localised refugia (Suggitt *et al*. 2014; Maclean *et al.* 2015). These areas will become increasingly important components of any nature network, helping species to persist under climate change and facilitating the spread of species, by providing 'islands' of relatively unusual environments, as the wider countryside changes under climate change (Suggitt *et al.* 2014).

Where new core sites are being proposed, they should aim to have the characteristics of high quality sites, as described above in section A2.3.1.1. **Thus, a single large site is normally preferable to several small sites**. However, several small sites can be beneficial in certain circumstances (Ovaskainen 2002), for example: to improve the connectivity between core sites (see A2.3.2.2 below) when large parcels of land are not available; where populations do not fluctuate in parallel between sites, such that if extinct populations on one site, can be re-colonised by individuals from another; and several small sites can spread the risk of rare, catastrophic events ('all your eggs are not in one basket'). The 'habitat amount hypothesis' (Fahrig 2013) suggests that the total amount of a habitat is the key aspect for increasing species richness, rather than the size and configuration of habitat patches within a landscape. Although there is some support for this (e.g. Melo *et al.* 2017), this is still controversial and tests of this hypothesis support the need for bigger and more connected sites to support greater species richness (Haddad *et al.* 2017; Seibold *et al.* 2017; Evju & Sverdrup-Thygeson 2017).

[38] It should be noted that Sites of Special Scientific Interest (SSSIs) have conservation interest that must be protected despite the land often being used for other purposes; they also include sites designated for important geological features that can have a valuable function for biodiversity.
[39] http://ec.europa.eu/eurostat/statistics-explained/index.php/Biodiversity_statistics#Habitats (accessed 2/2/19)

When considering the addition of more sites, it is important to note that **increasing the number of sites within an area will not be effective if connectivity between sites is poor** (Johst et. al. 2011). The provision of more sites is particularly important for metapopulations in which the **extinction rates on patches are greater than colonisation rates**, for example where habitat fragmentation affects butterfly populations on calcareous grassland (Skirvin *et al.* 2013).To ensure that there is **sufficient genetic diversity** within populations, there needs to be **at least 1-10 immigrants per generation** into each site (Mills & Allendorf 2002).

<u>Improving core site protection</u>: **Ecological continuity** is an important consideration – areas of land that have not been managed intensively and have had the same cover of a particular ecosystem type for a long period of time develop characteristics of species richness and special soil conditions that are of conservation importance (Norden *et al*. 2014). Although already likely to be contributing to a nature network, the loss of such sites would have a disproportionate impact on the value of a network. Ancient woodland (defined as having been present since at least 1600 A.D.) is perhaps the best known of this type of habitat in England (Peterken 1977) and commonly contains species that are less frequently found in secondary woodland (e.g. Ellis 2015). In a detailed review of woodland studies, Humphrey *et al.* (2015) found that ecological continuity was important for vascular plants and lichens, but had only been assessed in a few vertebrate (e.g. dormice) and invertebrate studies (e.g. saproxylic beetles).

Areas of other types of habitat that have long histories have also been found to be more biodiverse than more recently established similar habitats (e.g. ancient heathlands – Forup *et al.* 2008; ancient calcareous grasslands – Fagan *et al.* 2008; wood-pasture and parkland - Harding and Rose 1986). Human activity and landuse changes can have particularly important impacts on soil microbial communities that may be very long-lived (hundreds of years), with follow-on impacts for ecosystem services such as carbon storage and nutrient cycling (Fichtner *et al.* 2014). In such cases, land managers should consider maintaining the traditional landuse practices (Crofts & Jefferson 1999; Plieninger *et al.* 2006) or substituting them with a more 'natural' ecosystem processes that mimic the traditional landuse practice, for example the reintroduction of grazing on heathland sites (Newton *et al.* 2009; Fagúndez 2013); and the value of rabbit *Oryctolagus cuniculus* grazing on grassland sites (Brereton *et al*. 2008; Isermann *et al.* 2010).

Finally, there are a range of other conservation sites that may be relatively unprotected and under-managed such as Local Wildlife Sites and Local Geological Sites (Lawton *et al.* 2010). Local Wildlife Sites are non-statutory, having only minimal protection through recognition in national planning policy, and are highly vulnerable to damage and loss. They can be used to influence the direction of agri-environment funds but in general their management is under-funded. Local Wildlife Sites are potentially important to future nature networks, because they not only provide wildlife refuges in their own right but can act as stepping stones and corridors to link and protect nationally and internationally designated sites. Thus their loss could be detrimental, so biodiversity conservation would benefit from providing greater protection to such areas, thereby increasing the core component of a network.

A2.3.2.2 *Improving connectivity ('Joined')*: Wildlife sites within a nature network can be connected in three main ways:

- Functionally by mobile species, through the means of 'stepping stones' - patches of suitable habitat that are transiently used areas between two large wildlife sites; or
- through the 'matrix' –i.e. the land between sites, which can be more or less 'permeable' for the movements of species, but cannot be classed as 'habitat' where the organism can live and sustain itself for periods of time (Ament *et al.* 2014).
- Physically, by corridors of habitat that is similar to that found in the core sites which they connect.

As a note of caution, it should be remembered that increasing connectivity may not always be desirable. In some cases, particularly for freshwater systems, there will be the risk that increased connectivity might facilitate movements of non-native invasive species into sites (Knight *et al*. 2014).

Stepping stone networks can promote population persistence by supporting the movement of plants and animals between large blocks of suitable habitat (e.g. Baum *et al.* 2004; Doerr *et al.* 2014; Fischer *et al.* 2006; McConkey *et al.* 2012). These are essentially sub-optimal areas that aren't suitable for maintaining populations sustainably, but do provide sufficient resources to allow individuals to use them as way-stations *en route* between core sites. They may be as small as a single tree. **Stepping stone areas need to be big enough** to be colonised by relatively immobile species, such as plants, but also not to be ecological 'traps' – superficially suitable, but not sufficiently big or well-connected enough to allow onward movement or the production of propagules (Saura *et al.* 2014). The creation of multiple small patches also has the potential advantage in that they can be provided in situations where the provision of larger blocks of habitat might not be practically possible within a landscape (Rosch *et al.* 2015).

If the matrix that surrounds core sites is not too hostile, then certain species can move through it, even though it is unsuitable for them to live in permanently. This is described as **matrix permeability.** A matrix that is structurally or biologically more similar to the organism's 'home' or breeding habitat is more permeable to species movement (Eycott *et al.* 2008). However, a good example of how an apparently hostile environment can still be permeable, is shown by the way that dormice, thought to be restricted to woodland and hedgerows, will travel considerable distances (250-500m) across open fields to reach new blocks of habitat, as shown by a mark-recapture study (Büchner 2008). This reinforces the point made by Manning *et al*. (2004) that we should not make assumptions about how other species perceive the environment – ideally our views of permeability should be evidence-based. The matrix is also important in affecting the value of stepping stones and corridors (Baum *et al*. 2004) so it needs to be considered as an integral part of the nature network when designing strategies to improve connectivity (Prugh *et al.* 2008). It is important not to think of the habitat patch and matrix as an 'either/or' system –in many cases there is a continuum – a gradation of habitat suitability as patch merges into matrix, or if the matrix is actually quite favourable to a species. Thus habitat patches should not necessarily be thought of as 'islands' in a hostile 'sea' of non-habitat (Manning *et al*. 2004).

Improving the permeability of the landscape can be done by **reducing the intensity of farming practice**, **improving the diversity of land use** or by **increasing the amount of semi-natural habitat and 'messiness'** within a landscape. Peterken (2002) suggested a rule of thumb that a landscape should contain 30% woodland cover to ensure connectivity for woodland mammals, although this is a relatively simplistic rule (Taylor *et al.* 2006). Specialist woodland species with poor dispersal respond best to increasing landscape permeability (Humphrey *et al.* 2013). Van Teeffelen *et al.* (2012) suggested that between 20-60% of the landscape should be covered in suitable habitat to ensure connectivity between core sites - the higher thresholds occurring for species with poor dispersal abilities. Ruffell *et al.* (2012) suggested that at least 10% cover is required to reduce species loss in forest fragments. The impact of permeable land cover will be context-specific and depend on its configuration and placement - but **a general rule of thumb suggests at least 20% cover of semi-natural habitat** would help to improve connectivity and resilience of populations in the wider countryside and in core sites.

To ensure adequate connectivity between core sites or stepping stone areas, placement is important. Many studies have explored the effect of isolation on the likely colonisation rates of different taxa between patches of suitable habitat, and Table A2.3.2.2 provides a useful summary of evidence relevant to England. It should be noted that dispersal will be moderated by the relative permeability of the intervening matrix. However, in can be concluded that **for habitat-specialised species, adjacent habitat patches need to be < 200m apart and for more generalist species < 1 km apart.**

Table A2.3.2.2 Illustrative examples of the maximum distances required to allow the regular dispersal or colonisation of species from one block of habitat to another

- Woodland specialist vascular plant seed dispersal: <200 m (Peterken 2002; Jacquemyn *et al*. 2003)
- Dormice: <1000 m (Bright *et al.* 1994, Peterken 2002)
- Red Squirrels : <600 m (Peterken 2002)
- For woodland flora and fauna: <2 km (Humphries *et al.* 2013)
- For specialist species in semi-natural habitats there is a gap crossing threshold of c. 100 m and stepping stones appear to be more effective than corridors in this situation (Doerr *et al*. 2010).
- For specialist species (mainly birds and mammals) in semi-natural habitats, there is an inter-patch crossing threshold (using all available stepping stones and corridors) of c. 1100 m (Doerr *et al.* 2010).
- Snakes and amphibians appear to have a maximum dispersal distance of 1 km (Vos & Chardon 1998)
- Chalk grassland macro-moths benefit from recreation of grassland patches that are < 1 km from a large area (>10 ha) of calcareous grassland (Alison *et al.* 2016)
- Colonisation of arable land that is reverted to grassland by invertebrates is most successful if <500 m from an existing patch of species rich grassland and at most 2 km distant (Woodcock *et al.* 2015)
- Snails show reduced colonisation of patches > 100 m apart (Knop *et al.* 2011)

Habitat corridors that link core sites, have been the subject of considerable controversy, but a wide range of evidence suggests that, depending on their vegetation structure, size, configuration and management, corridors can be effective for maintaining populations of a wide range of taxa and for facilitating the ecosystem services that they provide (e.g. Bailey 2007; Doerr *et al*. 2010; Eycott *et al.* 2008; Eycott & Watts 2011; Gilbert-Norton *et al.* 2010; Humphrey *et al.* 2013; Tewksbury *et al.*2002). **Habitat corridors are a way to enhance landscape connectivity** for some plants and their dispersal agents, **when other options are not available**, particularly for dispersers that are habitat-specialists or have low mobility. However, they do not work in all situations, some species may be more likely to use them than others, and their usefulness may depend on their composition, length and width as well as the matrix in which they sit. In addition, we may see the world in a different way to the animals that we are designing corridors for – as shown by the general ineffectiveness of road crossings designed for animals (Eycott & Watts 2011), so natural corridors, built along natural features (such as rivers), are to be preferred where available. They may also be useful as an engagement tool with landowners when all other better ecological options have been exhausted.

Well-designed habitat corridors have, on balance, been shown to be effective in improving the connectivity between core sites for a wide range of species, increasing movement rates by c. 50% (Skirvin *et al*. 2013), and are potentially important for habitat specialists and immobile species, particularly plants (McConkey *et al.* 2012).

The design of corridors needs to take into account the following:

- **Natural corridors are more effective than human-designed corridors** (Gilbert-Norton *et al*. 2010).

- **The habitat in a corridor needs to be as close in type to the habitats in core sites as possible** (Eycott *et al*. 2008)

The width of the corridor is important, because being linear habitats, they will be affected by edge effects. For some small species, corridors as narrow as 1-2m may be sufficient (Andreassen *et al.* 1996), but for species that are 'corridor dwellers', that have to live in the habitat in order to propagate along it to eventually colonise the distant core site, the corridor needs to be as wide as a typical home range (Beier *et al.* 2008). Edge effects reviewed above (A2.3.1.2) can penetrate as far as 200m into a habitat, although most pronounced nearer to the edge, and this suggests that corridors should be at least 100m wide and probably more than 200m wide to provide a largely unaffected interior habitat (see section A2.3.1.2). Doerr *et al.* (2010) recommended that corridors should be >350m wide to provide sufficient good quality habitat to allow species to disperse successfully along it. In conclusion, **corridors need to be designed with specific species in mind, but a corridor of at least 100 m wide is likely to be a minimum width requirement.**

A2.3.2.3 *Other landscape-scale influences*: At the same time as considering the number of patches in a landscape and how they connect, we also need to think about a number of other landscape-scale influences on a nature network. A range of inter-related **physiographic factors** such as geology, topography, soils and hydrology can be very influential on species distributions (Anderson & Ferree 2010; Beier & Brost 2010). This is most clear for species that have a narrow range of ecological tolerances, for instance for those that rely on calcareous soils or highly acidic soils, but the principle also applies more generally. Consideration of how habitats and ecosystems would be naturally positioned in the landscape is therefore a key consideration in planning nature networks – this is discussed further in 3.4

The amount of semi-natural habitat in the landscape can be an important factor in helping populations in core sites to maintain themselves. Zulka *et al*. (2014) found that the area of grassland in the landscape surrounding high quality grassland patches was a significant predictor of species richness, and that the importance was about twice as great for specialist species than for non-specialist species. Bird and butterfly populations are more resilient to climate change in landscapes containing more semi-natural habitat (Oliver *et al.* 2017) and Newson *et al.* (2014) found that generalist woodland birds (those that are also found commonly in other habitats) were affected by the amount of woodland in a landscape, whereas specialist woodland birds (more restricted to woodland) were influenced by both the amount of woodland on a site as well as in the surrounding landscape. Ruffell *et al.* (2017) found that increasing the cover of non-native woodland in a landscape to above 10% helped to reduce the losses of species from patches of fragmented native woodland.

Landscape-scale habitat mosaics can be important for many wider-ranging species that do not confine themselves to one type of habitat. For a small invertebrate, all its requirements may be met within a relatively small radius, but larger invertebrates may travel further afield and certainly mammals and birds can travel very long distances. Species may make use of habitat patches that are separated by intervening areas of relatively unsuitable habitat, while others may make use of a variety of habitats. For example, bumblebees may forage for nectar along hedges, in trees or in arable crops, but return to their nests in patches of rough grassland; wintering pink-footed geese *Anser brachyrhynchus* may travel long distances from estuarine roost sites to feed on farmland many miles inland.

Interestingly, in agricultural areas, a more heterogeneous landscape can help to counter the impacts of intensive farming practices and reduce biological homogenisation, with its detrimental impacts on ecosystem functioning (Gamez-Virues *et al*. 2015). **Landscape-scale mosaics can also help improve the stability of populations**, presumably by ensuring a variety of suitable resources. For example, British butterflies in landscapes that contain a variety of suitable habitat types have more stable population dynamics than those in more uniform landscapes (Oliver *et al.* 2010). Habitat mosaics do not have to be fixed in space and time, and are likely to be more natural if allowed to be dynamic. This is encapsulated in the 'shifting-mosaic steady state' idea of Bormann & Likens (1979), that although the vegetation present at individual points in the landscape might change, when averaged over a sufficiently long time or large area, the proportion of the landscape in each successional stage is relatively constant.

Thus a landscape that has a good variety of different types of habitat can often support a greater variety of species than would be predicted by just considering the number and type of habitats present (Bennett *et al.* 2006).

A2.3.2.4 *Wider countryside species*: The factors listed above also apply to species that occur more generally within the wider countryside, but at a larger spatial scale. The habitats are less likely to be specially protected (such as hedgerows or small copses of trees within farmland), or maybe entirely anthropogenic in origin (e.g. cropped arable fields or lowland pasture), but the species that rely on them still need sufficient habitat and food resources to maintain their populations. In many cases this requires a reduction in pressures, such as reduced pesticide use, or the provision of extra resources (such as food or places to nest or shelter), which can be delivered through the deployment of appropriate agri-environment funding options (see section 3.3). A key consideration here is the need to provide all the fundamental resources needed by wider countryside species (i.e. year-round food supplies and habitats that provide nesting, hibernation and sheltering sites) in reasonably close juxtaposition to allow such species to survive and thrive (e.g. through the deployment of relevant bundles or packages of agri-environment scheme options). New research also suggests that areas of low-yield farming within a landscape may be important for some species that don't thrive so well in either semi-natural habitats or intensively farmed habitats (e.g. Linnet *Linaria cannabina*, Stock Dove *Columba oenas* and Grey Partridge *Perdix perdix*; Finch *et al*. 2019).

Agri-environment options have been shown to be successful in improving the population status of wider countryside species such as rare farmland birds, bees and plants (Pywell *et al.* 2012), widespread farmland birds (e.g. Dallimer *et al.* 2010, Baker *et al.* 2012, McHugh *et al.* 2018, Walker *et al.* 2018), macro moths (e.g. Alison *et al*. 2016), carabid beetles (Woodcock *et al.* 2007), bumblebees (Carvell *et al.* 2007) and small mammals (Broughton *et al.* 2014), as well as for targeting wider countryside species with more specific needs (e.g. Cirl Buntings *Emberiza cirlus* and associated invertebrates and plants, MacDonald *et al.* 2012). Importantly, the success of the implementation of agri-environment options is influenced by social factors affecting famers who learn how best to deliver these options (McCracken *et al.* 2015). In addition, there can be compromises required when designing aspects for wider countryside biodiversity, such as when managing grass margins alongside watercourses for both invertebrates and birds (e.g. McCracken *et al*. 2012).

Appendix 3 Practical aspects of Nature Network implementation

A3.1 Useful extracts from the National Planning Policy Framework (NPPF) for England with respect to implementing Nature Networks.

(Numbers refer to the paragraph numbers in the NPPF; Ministry of Housing, Communities and Local Government 2018).

8. Achieving sustainable development means that the planning system has three overarching objectives, which are interdependent and need to be pursued in mutually supportive ways (so that opportunities can be taken to secure net gains across each of the different objectives):….

> c) **an environmental objective –** to contribute to protecting and enhancing our natural, built and historic environment; including making effective use of land, helping to improve biodiversity, using natural resources prudently, minimising waste and pollution, and mitigating and adapting to climate change, including moving to a low carbon economy.

20. Strategic policies should set out an overall strategy for the pattern, scale and quality of development, and make sufficient provision (in line with the presumption in favour of sustainable development) for:….

> d) conservation and enhancement of the natural, built and historic environment, including landscapes and green infrastructure, and planning measures to address climate change mitigation and adaptation.

96. Access to a network of high quality open spaces and opportunities for sport and physical activity is important for the health and well-being of communities…..

98. Planning policies and decisions should protect and enhance public rights of way and access, including taking opportunities to provide better facilities for users, for example by adding links to existing rights of way networks including National Trails.

99. The designation of land as Local Green Space through local and neighbourhood plans allows communities to identify and protect green areas of particular importance to them…..

102. Transport issues should be considered from the earliest stages of plan-making and development proposals, so that:…

> c) opportunities to promote walking, cycling and public transport use are identified and pursued;
>
> d) the environmental impacts of traffic and transport infrastructure can be identified, assessed and taken into account – including appropriate opportunities for avoiding and mitigating any adverse effects, and for net environmental gains;

104. Planning policies should:…..

> d) provide for high quality walking and cycling networks and supporting facilities such as cycle parking (drawing on Local Cycling and Walking Infrastructure Plans);

118. Planning policies and decisions should: a) encourage multiple benefits from both urban and rural land, including through mixed use schemes and taking opportunities to achieve net environmental gains-such as developments that would enable habitat creation or improve public access to the countryside'

170. Planning policies and decisions should contribute to and enhance the natural and local environment by:

a) protecting and enhancing valued landscapes, sites of biodiversity or geological value and soils…;

b) recognising the intrinsic character and beauty of the countryside, and the wider benefits from natural capital and ecosystem services-including the economic and other benefits of the best and most versatile agricultural land, and of tress and woodland;

c) maintaining the character of the undeveloped coast, while improving public access to it where appropriate;

d) minimising impacts on and providing net gains for biodiversity, including by establishing coherent ecological networks that are more resilient to current and future pressures;

171. Plans should … allocate land with the least environmental or amenity value, where consistent with other policies in this Framework; take a strategic approach to maintaining and enhancing networks of habitats and green infrastructure; and plan for the enhancement of natural capital at a catchment or landscape scale across local authority boundaries.

172. Great weight should be given to conserving landscape and scenic beauty in National Parks, the Broads and AONBS, which have the highest status of protection in relation to these issues. The conservation of wildlife and cultural heritage are important considerations in these areas and should be given great weight in National Parks and the Broads….

174. To protect and enhance biodiversity and geodiversity, plans should:

a) Identify, map and safeguard components of local wildlife-rich habitats and wider ecological networks, including the hierarchy of international, national and locally designated sites of importance for biodiversity; wildlife corridors and stepping stones that connect them; and areas identified by national and local partnerships for habitat management, enhancement, restoration or creation (where areas that are part of the Nature Recovery Network are identified in plans, it may be appropriate to specify the types of development that may be suitable within them); and

b) promote the conservation, restoration and enhancement of priority habitats, ecological networks and the protection and recovery of priority species; and identify and pursue opportunities for securing measurable net gains for biodiversity.

175. When determining planning applications, local planning authorities should apply the following principles:

a) if significant harm to biodiversity resulting from a development cannot be avoided (through locating on an alternative site with less harmful impacts), adequately mitigated, or, as a last resort, compensated for, then planning permission should be refused;…

c) development resulting in the loss or deterioration of irreplaceable habitats (such as ancient woodland and ancient or veteran trees) should be refused unless there are wholly exceptional reasons and a suitable compensation strategy exists; and

d) development whose primary objective is to conserve or enhance biodiversity should be supported; while opportunities to incorporate biodiversity improvements in and around developments should be encouraged, especially where this can secure measurable net gains for biodiversity.

176. The following should be given the same protection as habitats sites:

a) potential Special Protection Areas and possible Special Areas of Conservation;

b) listed or proposed Ramsar sites; and

c) sites identified, or required, as compensatory measures for adverse effects on habitats sites, potential Special Protection Areas, possible Special Areas of Conservation, and listed or proposed Ramsar sites.

177. The presumption in favour of sustainable development does not apply where development requiring appropriate assessment because of its potential impact on a habitat site is being planned or determined.

204. Planning policies should:

a) provide for the extraction of mineral resources of local and national importance, but not identify new sites or extensions to existing sites for peat extraction;….

h) ensure that worked land is reclaimed at the earliest opportunity, taking account of aviation safety, and that high quality restoration and aftercare of mineral sites takes place.

A3.2 Examples of working with natural processes

A3.2.1 Small headwater catchments that are relatively hydrologically isolated

Field drainage can be removed and ditches blocked to provide good natural soil wetness gradients, channelized streams can be restored to natural geomorphological function, and grazing regimes can be reduced in intensity. These actions provide excellent opportunities to restore flush and mire habitats, in open and wooded situations, alongside other drier grassland, wood and scrub habitats and naturally functioning streams and pools. Renaturalisation here not only benefits biodiversity of these areas but also all water-related habitats downstream (including floodplain habitats that require good quality inundation waters), as well as maximising water-related ecosystem service benefits to as wide an area as possible.

Examples of small headwater catchments within a woodland setting (Photos by Chris Mainstone, Natural England)**.**

A3.2.2 River and coastal floodplain fringe areas. Whilst large-scale restoration of natural ecosystem function provides the greatest biodiversity benefits in floodplains, there are usually considerable constraints to this, particularly in the lowlands, and naturalisation of areas of floodplain fringe is more achievable (wider restoration is possible in small floodplains where the hydrological implications are limited and infrastructure is minimal). Catchdrains are drains that run along the base of the valley side and catch all of the springs and flushes as they reach the floodplain – they are typically linked to under-drainage of the adjacent lower slope of the valley side, all of which eliminates flushes and fen. The drains can be removed to restore a natural hydrological gradient from above the spring line to the floodplain fringe – this can be achieved without affecting the use of the wider

Upland catchdrain on lower valley slope (Photo by Iain Diack, Natural England) floodplain (which may be under intensive agriculture or urban development). Immediately adjacent to the river, estuary or sea, setting back existing flood defences can allow restoration of strong natural environmental gradients (in hydraulic energy, sediment erosion and deposition and, near the coast, salinity) that shape diverse natural habitat mosaics. Many good examples exist of coastal realignment (e.g. MacDonald *et al.* 2017) and river restoration schemes. Low-intensity vegetation management can create a pattern of open, scrub and wooded habitats to complete the habitat mosaic.

A3.2.3 Targeted areas of moorland fringe. Whilst there is considerable effort being invested in hydrological restoration of blanket bog for multiple biodiversity and socioeconomic benefits (water quality, flood risk management), less attention is being paid to the moorland fringe. There is considerable potential for delivering integrated biodiversity objectives through restoring woodland and scrub to ghylls denuded by prolonged and heavy sheep grazing. This restores stability and habitat diversity to stream channels, helps protect the integrity of the moorland habitat above (e.g. from ghyll incision), regenerates valley head mire habitat and further improves downstream water quality and flood risk. In addition, targeted alleviation of grazing pressure around the moorland enclosure line more generally would allow natural scrub and tree recolonisation, creating a mosaic of open, scrub and woodland habitats with natural wetness gradients, including a wide range of niches for birds and invertebrates characteristic of the moorland fringe (e.g. black grouse and marsh fritillary).

Natural Alder regeneration (Photo by Chris Mainstone, Natural England)

In any landscape, **individual hydrological pathways** can be naturalised from their source to create smaller-scale naturally functioning habitat mosaics with flush, mire, open water, and wet and dry grassland, scrub and woodland. This allows such mosaics to exist even in intensively managed landscapes, because the area of land required is small relative to the area of intensively managed land. This is easier to achieve in more hilly landscapes where individual natural hydrological pathways have a limited spatial influence on adjacent land use.

Small-scale habitat mosaic beside a stream (Photo by Chris Mainstone, Natural England)

At a smaller-scale, any areas of existing semi-natural habitat can be looked at in terms of the micro-habitat they provide. For instance, have natural streams, flushes and small areas of fen been eliminated from an ancient woodland by historical drainage? Is the grazing regime providing patches of bare ground necessary for the long-term sustainability of the grassland sward or associated invertebrates? Restoring these lost elements of natural function can greatly enhance the contribution of these areas to nature networks, restoring missing habitats that are essential to different native species.

A3.3 Restoring more natural ecosystem processes

Principle 4 in Appendix A1.4 discusses the need to build nature networks around existing high quality sites and to work with functional ecological units. Such units are those in which natural processes are freer to operate, being more self-sustaining and providing greater resilience. Table A3.3, below, builds on this and the information in section 3.4 and Appendix A3.2 to outline how to choose what habitats to restore, and where and how.

Table A3.3 Restoring natural processes – the range of different aspects involved

1. **Consider larger spatial and ecological scales, whilst recognising the importance of small-scale ecological detail in evaluation and management decision-making – habitats form natural dynamic mosaics in the landscape which we need to recognise and conserve.** *Working at larger scales provides more options in where the habitat niches of individual species are met. This helps when restoration of some aspect of natural ecosystem function removes existing niches from a location. With careful planning, if required niches are provided across the larger area, then multiple biodiversity objectives can be satisfied. However, whilst it's important to think at larger scales, practical action is often undertaken at smaller spatial scales.*
2. **Understand how abiotic processes (particularly hydrology) would function naturally in the landscape in the absence of human modifications and use this as a starting point for biodiversity planning.** *It is impossible to plan for more naturally functioning landscapes if there is no clear understanding of how the landscape could function naturally. This is particularly important in relation to the movement of water through the landscape, in terms of surface and sub-surface pathways and the natural behaviour of groundwater. For freshwater and coastal habitats it is important to understand natural dynamic sediment erosion and deposition patterns.*
3. **Understand how ecological relationships (between habitats, between habitats and species, and between species) would operate in the landscape under natural abiotic processes, and use this for planning semi-natural habitat mosaics.** *It is vital to start with an environmental template which shows the potential for habitat provision, to get a good idea of where we should be aiming to provide different habitats. This is particularly important for planning the relative positions of wet and dry habitats, but also in terms of the influence of other key environmental gradients such as salinity and temperature (e.g. climatological limits of scrub and woodland development in the uplands).*
4. **As part of understanding ecological relationships, consider how biotic processes (particularly herbivory) would function naturally, and use this to help refine the spatial framework.** *Allow for natural colonisation and regeneration (including patches of bare ground), transitional vegetation between formal habitat types, and dynamism in the spatial pattern of open, scrub and wooded habitats. These processes are generally less governed by precise landscape position and are more random in their expression, implying greater management choice and flexibility than with natural abiotic processes.*
5. **Most habitats are actually habitat mosaics, and it is critical to maintain these for nature conservation.** *Recognise that habitat variation occurs at a range of spatial scales, from micro- to macro-scale, all of which is critical to the provision of habitat niches for our native species complement. Our use of habitat classifications over-simplifies this variation and can lead to a lack of consideration of finer-scale detail. Small patches of one habitat (e.g. flush or fen) can be subsumed into larger 'parent' habitats (e.g. woodland) and their conservation at site-level can be neglected.*
6. **Understand what individual habitat types and species need, but don't be bound by historical precedent.** *This is about not being unnecessarily prescriptive about which habitats and species should be where, based on their recent history. They may be located in positions that result from historical factors that we should be seeking to resolve. For instance, the scarce blue-tailed damselfly may currently be present in a ditch formed by drainage of a heath, but it*

might thrive better in wide range of locations in a restored, naturally functioning mosaic of wet and dry heath and bog.

7. **Think about how naturally functioning habitats can deliver the requirements of individual species.** *This is about understanding the natural habitat niches of individual species, and planning to provide them in restored naturally functioning habitat mosaics. This is not about specifically creating optimal conditions for individual species by tailored habitat management, but rather by encouraging the ecosystem processes whereby suitable conditions will be provided. In the example of the scarce blue-tailed damselfly, the natural niche is small pools in heathland, which are generated by naturally functioning wet heath. The natural niche of some species is not necessarily well-understood and may require further research.*
8. **Recognise that the balance of habitat types within habitat mosaics, and species within assemblages, will change as a result of restoring elements of natural function – focus on the integrated biodiversity benefits across all habitats and species.** *This is about recognising that naturally functioning habitat mosaics have environmental carrying capacities, and that species benefiting from modifications such as drainage and intensive grazing regimes are likely to decline in number and extent if elements of natural function are restored. These changes need to be accepted as part of restoring balanced naturally functioning habitat mosaics that cater for our full species complement.*

A3.4 Selected list of published practical guides on habitat restoration and creation

(N.B. This is not an exhaustive list and notes about some documents are made in italics).

General

- Andrews, J. & Rebane, M. (1994) ***Farming & Wildlife: A practical handbook for the management, restoration and creation of wildlife habitats on farmland.*** RSPB, Sandy.
- Ausden, M. (2008) Habitat ***Management for Conservation: A Handbook of Techniques*****.** Oxford University Press, Oxford.
- Buglife: ***Managing priority habitats for invertebrates***. https://www.buglife.org.uk/advice-and-publications/managing-priority-habitats-invertebrates (Accessed 14/12/18) - '*These pages provide advice for 32 priority habitats in England'.*
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Coastal

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Appendix 4 Further details of mapping and decision support tools for use in planning nature networks

A4.1 Contact details

Contact Information - The use of maps, tools and models, the range of available data and the licence issues that go with them, is often confusing and it can sometimes be unclear how you get hold of the information you need. Data and tools are also constantly changing as websites get updated and new approaches become available. We have tried to be as up to date as possible in this chapter, but we know things will change. We plan to update this Handbook as things change, but please do contact us to discuss any of the data and tools discussed above: Sarah Taylor – sarah.taylor@naturalengland.org.uk Ian Crosher – ian.crosher@naturalengland.org.uk Natural England Open Data Portal – http://naturalengland-defra.opendata.arcgis.com/ Natural England Data Services – data.services@naturalengland.org.uk

A4.2 Mapped data

A4.2.1 Climate change refugia maps http://publications.naturalengland.org.uk/publication/6659217335255040?category=10003 (Accessed 8/2/19)	
Aims and Audience	**What is the aim of the mapping?** To identify properties of the landscape that contribute to climate change refugium potential and display mapped analysis of the location of high to low potential for these refugia. **Who is it primarily aimed at?** Conservation practitioners, researchers and policy makers. **What data is used to create the maps?** Species persistence or extinction data from CEH Biological Records Centre (BRC). Changes in climate variables - temperature, snow cover, precipitation (from UKCP09 – see https://www.metoffice.gov.uk/research/collaboration/ukcp).

	Landscape variables/potential predictors of refugia – geology, topography, cold air flow, water availability, surface temperature (solar index) and land cover (to show agricultural intensity).
Approach	**What method does the model use? T**he approach assembled national datasets of species persistence at the 10 km cell (or hectad) level and tested for associations with environmental variables that a literature review had identified as being indicative of refugia. Using statistical models, the variables that best identified areas of persistence over the last 40 years were established, both (a) across the biota, in an 'all species' approach, and (b) by taxon. The statistical approach allowed the relative effect sizes of these variables to be compared, disentangling and highlighting the drivers of species occurrence. The statistical models also generated refugia maps, identifying the areas most likely to host refugial populations of species under climatic change. These maps are Geographical Information Systems (GIS) ready and hence can be easily included in national conservation planning exercises. Finally, the approach provided a preliminary assessment of the overlap between these refugia and the English protected area network (Sites of Specific Scientific Interest, National Nature Reserves, National Parks), to assess the extent to which refugia are protected by existing statutory legislation. Analysis were carried out and maps produced for 'all refugia' (using all possible refugia variables), 'climate change and microclimate refugia' (excludes geological and agricultural intensity variables) and 'microclimate refugia' (excludes geological, agricultural intensity and climate change variables) for all species and taxon groups. Please see the report for more information. **At what scale can it operate?** National, 10 km x10 km grid; mapping was tested at the landscape scale (1 km squares), but was limited by the availability of fine-scale species data. **Are there any important limitations of the mapping?** Input data quality issues (as with all data and tools). The modelling process does not include other factors that are likely to have affected species distributions and population persistence, especially nitrogen deposition, agricultural intensification and broader landuse change. The 'all species' analyses are strongly affected by vascular plants, which comprised nearly 50% of the sample.
Coverage	**What habitats, species, ecosystem services, access for people or landscape considerations are covered?** Priority habitats are considered and a range of landscape variables are included in the analysis. **What potential exists to expand current coverage?** No potential, unless another project is run.
Potential for Combination	**Can the model be used in combination with other models and data?** Yes - this data can be used alongside other datasets. For illustrative purposes, displaying refugia data with the topographic heterogeneity results from the National Biodiversity Climate Change

	Vulnerability Assessment, highlights the most topographically varied and refugia rich areas, which may be most useful for the conservation of biodiversity under climate change.
Data Requirements	**Are there additional inputs of data required?** No. These are maps/data that are the results of analysis already carried out. **What are the time requirements for inputting data?** None. These are maps/data that are the results of analysis already carried out.
Transparency, interpretability, consideration of uncertainty and quality assurance	**How reliable and understandable are model outputs?** This dataset is for use by experts or with expert help. There are a series of limitations that must be understood and incorporated into thinking when using the data. The report can provide the detail required to interpret the data correctly, but time will be needed to understand everything required to make considered use of the data.
Intellectual property rights, data access and operating system requirements	**What are the requirements and limitations, in this respect, for using this model?** Currently not available online, contact Natural England (see above) for access.
Strengths	**What are the strengths of the maps?** It provides a visual display of areas of potential climate change refugia for species persistence that has not been shown before at a national scale.
Weaknesses	**What are the weaknesses of the mapping?** See limitations listed above. The maps could easily be misinterpreted, care and time is required to avoid this.
Examples	**Where has the mapping been used and for what?** The maps have been used in a pilot project that has explored the use of systematic conservation planning approaches for Natural England.

A4.2.2 Climate change risks and opportunities for species http://publications.naturalengland.org.uk/publication/4674414199177216?category=10003 (Accessed 8/2/19)	
Aims and Audience	**What is the aim of the mapping?** To present modelled assessments of the potential changes in the spatial distribution of climate suitability of species due to climate change. **Who is it primarily aimed at?** Conservation practitioners, researchers and policy makers. **What data is used to create the maps?** Climate envelope models using climate change projections and species distribution data from the

	Biological Records Centre (BRC), National Biodiversity Network (https://nbnatlas.org/) and British Trust for Ornithology (BTO) data.
Approach	**What method does the model use?** Statistical models linking species' distributions to climate were produced, and then used to assess the likely impacts of future climate change upon the potential distribution of climate suitability for the species. **Bioclimatic modelling** - A standardised climate envelope model was used across all taxa in order to ensure that cross-taxonomic comparisons were fair and unbiased by the methods used and to allow the automated assessment of 1000s of species. Four bioclimate variables were used to describe spatial variation in the climate using 1961-1990 averages; (1) mean temperature of the coldest month, as a measure of winter cold; (2) growing degree days, as a measure of the plant growth season; (3) the coefficient of variation of temperature, as a measure of seasonality; (4) soil moisture, as a measure of moisture availability. British scale models used observed climate data, on a 5 km × 5 km grid, from the period 1961-90 from the UK Met Office. To represent UK climate under global temperature changes of 2°C and 4°C with the spatially coherent projections, the following products were selected: 2070-99 for scenario B1 (2°C change) and 2070-99 for scenario A1B (4°C change) (from the UKCP09 see - https://www.metoffice.gov.uk/research/collaboration/ukcp). For European-scale models, observed climate data from the period 1961-90 were acquired from the Tyndall Centre for Climate Change Research; dataset CRU TS 1.2. All input data was scaled to fit a 10 km × 10 km grid. **Distribution data** - Distribution data were collected from BRC, NBN and BTO, primarily from 1970-89, and were used to determine species distribution. This time period was used because an increasing magnitude of climate change is recorded after this period which may affect species distributions recorded after this time (birds and plants are exceptions due to atlas dates). **Method** - The method used for the bioclimate modelling was devised by Beale *et al.* (2014). It involved the application of a Bayesian, spatially explicit Generalised Additive Model to species' distribution data in order to separate climatic, spatial and random components in determining the distribution of each species. Future projections of climate change were based on UKCP09 (see https://www.metoffice.gov.uk/research/collaboration/ukcp) projections for 2070-2099 for B1 and A1B models, equivalent to approximately 2°C vs. 4°C scenarios of global warming. See Pearce-Higgins *et al*. 2015 for more details. **Trend framework** - These projections were then compared to observed recent range changes, in order to assess the risk (within the recent historical distribution of each species) and opportunities (outside this area) for each species in a changing climate using a basic framework that was based on Thomas *et al.* (2011). A subset of 400 species were given a more comprehensive assessment, based on the full Thomas *et al.* (2011) framework.

	At what scale can it operate? National, 10 km x 10 km grid squares **Are there any important limitations of the mapping?** Climate envelope modelling has a range of limitations: • The relationship between present species distribution and climate may be weak if current distributions are determined largely by factors other than climate. • Climate change may result in climatic conditions for which there is no present day analogue, therefore projections based on the present climate will be unreliable. • Mapped climate or species distribution may not reflect the real life situation due to spatial resolution issues. • Distribution maps for some species may not be accurate. • Local climate variations and microclimates may provide conditions in which a species can survive locally, where one would not expect it to, based on larger scale patterns in climate. • Climate envelope models indicate where climate conditions may be suitable, but not whether a species can reach a new potential location or whether other requirements such as habitat or food supply will be available there. • Interactions between species may play a major role in determining climatic limits, these interactions are not included. Some of these limitations have been addressed by this project, see the report for more detail.
Coverage	**What habitats, species, ecosystem services, access for people or landscape considerations are covered?** >3000 species of conservation interest are modelled **What potential exists to expand current coverage?** No potential, unless another project is run.
Potential for Combination	**Can the model be used in combination with other models and data?** Yes. We envisage these data could be used alongside habitat network mapping to bring together potential changes in species range alongside the available or planned network of habitats. Long-distance species movement models, such as Condatis, may also be able to make use of the species envelope modelling presented in this analysis.
Data Requirements	**Are there additional inputs of data required?** No. These are maps/data that are the results of analysis already carried out. **What are the time requirements for inputting data?** None. These are maps/data that are the results of analysis already carried out.

Transparency, interpretability, consideration of uncertainty and quality assurance	**How reliable and understandable are model outputs?** This data is for use by experts or with expert help. There are a series of limitations that must be understood and incorporated into thinking when using the data. The project report and annexes can provide the detail required to interpret the data correctly, but time will be needed to understand everything required to make considered use of the data.
Intellectual property rights, data access and operating system requirements	**What are the requirements and limitations, in this respect, for using this model?** Currently not available online, contact Natural England (see above) for access.
Strengths	**What are the strengths of the maps?** The visualisation of potential future range changes is useful to get people thinking about how things may change in the future and what they may have to do in order to facilitate positive change if possible. If an area is crucial for the conservation of a species, these maps can provide illustrations of potential change and support the need to think about how species will need to adapt.
Weaknesses	**What are the weaknesses of the mapping?** See limitations listed above. The maps could easily be misinterpreted, care and time is required to avoid this.
Examples	**Where has the mapping been used and for what?** It has been used to help inform the 2nd edition of the NE/RSPB Climate Change Adaptation Manual – with maps included in the example species accounts (Natural England & RSPB 2020).

A4.2.3 Habitat Potential Data Layer (Morgan *et al*. 2016)	
Aims and Audience	**What is the aim of the mapping?** The **habitat potential areas** illustrate where appropriate conditions exist to support the creation of a habitat, i.e. it has qualities that suggest that creation and/or restoration is likely to be possible. **Who is it primarily aimed at?** Conservation practitioners and land use change planners. It provides spatial data on the potential location of habitats where restoration could be attempted. It is particularly useful for the development of ecological networks, improving the functioning of existing patches of habitat as part of a landscape scale restoration project, and enhancing ecosystem service provision. **What data is used to create the maps?** The analysis is based on the Priority Habitat Inventories and soils data (Cranfield University 2019). The process identifies soil types associated with habitat types, it also uses topography (slope) and location for some habitats.

Approach	**What method does the model use?** Step 1 **- Identify Suitable soils. Many habitats are closely associated with soil types (e.g. calcareous grasslands, heathlands and peat habitats). Some habitats also have physical constraints in terms of slope or location (i.e. coastal habitats restricted to the coast, upland habitats to the uplands). Step one identifies these associations:** 1. A GIS analysis determined the soil associations for habitats in Natural England's Priority Habitat Inventories. 2. The coincidence of habitat and soil types were then reviewed by expert judgement to check for ecological validity; reference was also made to the Natural England Research Report 712 on soils and habitat restoration (Bradley *et al.* 2006). 3. A small number of habitats did not have strong associations with any particular soil types e.g. woodpasture & parkland, traditional orchards, so these were not included. **Step 2** – Further refinement was undertaken, in some cases, using additional information, such as data from the Wetland Vision (Hume 2008) and Land Cover Data (*Morton et al*. 2011), along with slope and proximity to particular landscape features. For example, potential areas for Maritime Cliff and Slope habitat creation required information on topography and coastal proximity to be included. **Step 3** - Constraints to future habitat creation/restoration were identified, for example, urban areas were identified and excluded from the potential maps. **At what scale can it operate?** It is a national data set based on broad soils data, but is relevant at a regional and local scale. It is unlikely to be accurate at a field or small site level but may help with informing potential at this scale with local knowledge. **Are there any important limitations of the mapping?** The analysis was based on 296 geographic soil associations, usually a dominant soil series and related local ancillary soil series descriptions. Some habitats were associated with only a few of the soil descriptions in a series, but others were associated with all in a grouping of soil types. Consequently precision varies between different priority habitats and thus confidence levels also differ.
Coverage	**What habitats, species, ecosystem services, access for people or landscape considerations are covered?** Soil types are used to identify the potential for creation of priority habitat. **What potential exists to expand current coverage?** No potential, unless another project is run.

Potential for Combination	**Can the model be used in combination with other models and data?** Yes. It was developed by Natural England in combination with the National Habitat Network (NHN) Mapping approach (see below), therefore they directly link to one another. It would also work well with information on habitat fragmentation (e.g. from the NBCCVA – see below) which could illustrate where refinements to the potential areas could help focus habitat restoration to the most fragmented parts of an existing habitat patch (as in the NHN). Natural Flood Management data may also work well in combination, to identify areas to restore habitats that would also have ecosystem service benefits.
Data Requirements	**Are there additional inputs of data required?** No. **What are the time requirements for inputting data?** None
Transparency, interpretability, consideration of uncertainty and quality assurance	**How reliable and understandable are model outputs?** The output is a national scale map showing the habitat restoration/creation potential for the major priority habitats in England. Once the input datasets are understood (potentially suitable soil types), the maps are intuitive. As with all spatial data, the maps should be used with local knowledge and expertise to refine and interpret them.
Intellectual property rights, data access and operating system requirements	**What are the requirements and limitations, in this respect, for using this model?** The data is restricted under licence and needs to be accessed via Natural England, please contact - ian.crosher@naturalengland.org.uk
Strengths	**What are the strengths of the maps?** The maps based on high quality soil maps. They also show where degraded habitats can be restored to priority habitat quality. The maps are simple and intuitive and the method is transparent and easily understood. The scale makes them useful for national analysis and objective setting for future biodiversity restoration targets, but they are also useful at a landscape scale.
Weaknesses	**What are the weaknesses of the mapping?** Input data quality (in common with all tools). They will always be improved by incorporating local knowledge at a landscape scale.
Examples	**Where has the mapping been used and for what?** The habitat potential maps are currently being trialled by Natural England with Area Teams and Landscape Scale Pilot Areas.

A4.2.4 National Habitat Network Framework and Maps (Edwards *et al.* 2018)	
Aims and Audience	**What is the aim of the mapping?** Created by Natural England to create a straight-forward and repeatable method to produce habitat network maps that include components that address where there is potential to create or restore habitat and elements that help identify priorities for action. We created a project to develop a series of national habitat network maps for England based on priority habitat inventories. The habitat network mapping approach seeks to apply the best evidence and principles and to use the best available nationally consistent spatial data to create a series of maps that can then be used, alongside local knowledge, to plan habitat creation and restoration at a landscape scale. We have done this for 19 priority habitats so far. The maps show areas where appropriate conditions exist to support the creation of a habitat, i.e. it has qualities such as soil type that suggest that creation and/or restoration is likely to be possible and where these conditions exist **within close proximity** to the existing habitat network. **Who is it primarily aimed at?** Conservation practitioners and land use change planners e.g. Local Planning Authorities. It provides information on areas where habitat creation and restoration could best contribute to enhancing the current habitat network. The maps will contribute to landscape scale ecological network design and delivery and the approach can incorporate local knowledge and data. **What data is used to create the maps?** Priority habitat inventory, agri-environment scheme habitat creation and restoration locations, Soilscapes and National Biodiversity Climate Change Vulnerability Fragmentation data.
Approach	**What method does the model use?** The approach has been to create a framework that consists of five key components; 1) Primary habitat – Our first step is to identify the location of existing patches of priority habitat for the specific habitat network. 2) Habitat group – We then identified the location of other habitat types that form a mosaic or an ecologically coherent grouping that is used by species associated with the primary habitat. 3) Restorable areas and areas under restoration – Next we identified (a) areas that are classed in habitat inventories as degraded habitat types associated with the primary habitat and (b) areas that are currently undergoing appropriate habitat restoration work. 4) Network enhancement zone –This comprises three components which are developed by identifying buffering zones around habitats to identify clusters and create ‘network enhancement zones’ where actions to enhance current habitat networks could be targeted. This zone captures areas of degraded habitat, and areas with suitable soils

	surrounding existing priority habitat that are likely to be suitable for habitat restoration or re-creation and are in good locations to enhance and build the resilience of the current habitat network. 5) Priorities for restoration – Finally we identified two elements that are priorities for restoration: (a) small fragmented areas of existing habitat that have the potential to be enlarged or joined with other habitat patches and (b) links between sections of the network enhancement zones that have potential to join up parts of the network. **At what scale can it operate?** The maps can be produced at a range of scales. Initially they have been produced at the national scale, which will help ecological network planning at a strategic level. The national scale maps are useable at a local scale but the approach provides the ability to include locally derived data so the process can be carried out at a local scale to contribute to landscape scale planning and delivery, enhancing its flexibility and responsiveness.
Coverage	**What habitats, species, ecosystem services, access for people or landscape considerations are covered?** Priority habitats: the primary consideration is nature conservation. Maps have been produced for lowland calcareous grassland; upland calcareous grassland; reedbeds; coastal saltmarsh; coastal sand dunes; coastal vegetated shingle; maritime cliff and slopes; lowland meadows; upland hay meadows; purple moor-grass and rush pastures; lowland dry acid grassland; lowland heathland; upland heathland; lowland fens; lowland raised bog; blanket bog; wood-pasture and parkland; traditional orchards; and ancient woodland. **What opportunity exists to expand current coverage?** The analysis is currently relevant at all scales, but the approach is repeatable, providing the ability to include locally derived data at a local scale. This flexibility allows users to improve the accuracy of the mapping and refine input data as and when updated data is available further, thus increasing its usefulness at a finer scale. Some habitats are not covered and require further investigation before deemed suitable for this approach, these include coastal and floodplain grazing marsh; calaminarian grassland; limestone pavement; mountain heaths and willow scrub; upland flushes, fens and swamps; mudflats; saline lagoons; hedgerows; inland rock & scree; lakes; rivers; ponds; open mosaic habitats; and arable field margins.
Potential for Combination	**Can the model be used in combination with other models and data?** Yes. The Fragmentation data from the NBCCVA method has been used within the approach to highlight where action can be taken to reduce habitat fragmentation. Other datasets would also work alongside this dataset in order to identify a range of actions to address different elements of vulnerability or resilience building. Synergies can also be identified if this data is used alongside data, such as carbon storage and sequestration maps or locations to enhance natural flood risk management.

Data Requirements	**Are there additional inputs of data required?** Not to use the nationally produced maps, but local data can be included using the GIS framework and the analysis repeated. **What are the time requirements for inputting data?** None to use the nationally produced maps, but local data can be included in local analysis, this would require time to prepare the data, run the analysis and interpret the results.
Transparency, interpretability, consideration of uncertainty and quality assurance	**How reliable and understandable are model outputs?** The mapped outputs for each habitat are simple, understandable and intuitive. Further interpretation is required where more than one habitat exists in a location.
Intellectual property rights, data access and operating system requirements	**What are the requirements and limitations, in this respect, for using this model?** The maps can be viewed within GIS software, as PDFs and as open data via Magic. If local analyses are required, specialist GIS technical input will be needed.
Strengths	**What are the strengths of the maps?** The maps are the result of analysis that will help conservation practitioners identify where there is real potential carry out habitat creation and/or restoration to enhance the current priority habitat network. They also show where degraded habitats can be restored to priority habitat quality and where the smallest fragments of habitat can be made bigger and/or joined to other habitat patches. The maps are simple and intuitive and the method is transparent and easily understood. The data provided are useful for national analysis and objective setting for future biodiversity restoration targets. The supporting GIS framework also provides the ability to incorporate local scale data and re-run the analysis.
Weaknesses	**What are the weaknesses of the mapping?** Input data quality (in common with all tools).
Examples	**Where has the mapping been used and for what?** Maps are currently being trialled by Natural England with Area Teams and Landscape Scale Pilot Areas.

A4.2.5 Carbon storage and sequestration maps (*Spatial Prioritisation of Land Management for Carbon*, Natural England/AMEC, unpubl.)	
Aims and Audience	**What is the aim of the mapping?** To provide indications of priority areas where carbon can be retained or CO2 emissions reduced to mitigate for climate change. The **Carbon Storage** Priority data identifies and maps current carbon storage, highlighting areas of high carbon density in peat soils that require protection to prevent further carbon loss. The **Carbon Sequestration** Priority data identifies and maps future carbon storage potential where carbon storage could be increased with positive land use change (e.g. when changing from arable to grassland, carbon emissions from peat is significantly reduced). The datasets were created to highlight areas where agri-environment delivery can increase the amount of carbon that can be locked in the soil and therefore reduce greenhouse gas emissions. **Who is it primarily aimed at?** Land use and land management practitioners and those who carry our Countryside Stewardship targeting. **What data is used to create the maps?** The datasets are derived from NATMAP's Carbon national soil map (National Soil Map of England and Wales: http://www.landis.org.uk/data/natmap.cfm (accessed 8/2/19)), CEH Land Cover Survey data (Morton *et al*. 2011) and Natural England's Dudley Stamp Historical land use data (Hooftman & Bullock 2012).
Approach	**What method does the model use?** Soil C (Carbon) storage values given in the NATMAP Soil dataset (down to 1.5m) were manually assigned metrics (1-10) from low to high carbon, then amended using current and historical land use data (±2) to estimate current soil carbon levels. For sequestration potential, Land Cover data was used to select only Arable and Temporary Grassland land use classes, on which estimates of potential soil C are made by manually assigning metrics for soil carbon potential based on soil type (1-10), soil depth (±2, taken from NATMAP) and historical land use (±2). **At what scale can it operate?** 1:250,000 based on the spatial resolution of the source datasets. **Are there any important limitations of the mapping?** • The spatial resolution of the datasets is not as fine as the real world variation in soil type and condition; • The datasets are evidence-based estimates of soil carbon rather than real world measurements. • The simplification of the manual metrics to 3 classes (high, medium, low) masks some of the variation between different areas.

Coverage	**What habitats, species, ecosystem services, access for people or landscape considerations are covered?** Carbon storage and sequestration potential as an ecosystem service. **What potential exists to expand current coverage?** There may be potential, but no plans, to extend to other UK nations and/or to update with any new source data at present.
Data Requirements	**Are there additional inputs of data required?** No. **What are the time requirements for inputting data?** These are reference data and there are no inputting requirements.
Transparency, interpretability, consideration of uncertainty and quality assurance	**How reliable and understandable are model outputs?** To our knowledge they represent the best available data, however, they have not been calibrated to the 'real world'.
Intellectual property rights, data access and operating system requirements	**What are the requirements and limitations, in this respect, for using this model?** The data is under a licence to use the NATMAP source data and this must be renewed to allow continued use of the derived Carbon storage and Sequestration datasets, beyond the expiry of the current licence. As such you will need to contact Natural England to gain map copies & check licence requirements.
Strengths	**What are the strengths of the maps?** Easy visual identification of likely high priority areas for carbon storage and sequestration.
Weaknesses	**What are the weaknesses of the mapping?** Not real world tested. Data resolution is good, but finer scale variation between different soil types/land use histories is likely to occur. NATMAP Carbon only based on soil depths of up to 1.5 m. Where many peats can be 5 to 10m in depth so this underplays deeper peats. Some important areas like the East Anglian Fens and the Somerset Levels come out as lower priority due to having had a long period of cultivation and loss of carbon. This does hide how much potential they have to reduce emission by land use change i.e. 50% of UK peat emissions comes from England's Lowland Peat in cultivation.
Examples	**Where has the mapping been used and for what?** Included in the Countryside Stewardship Targeting system.

A4.2.6 Natural Capital Mapping (https://eip.ceh.ac.uk/naturalengland-ncmaps (Accessed 8/2/19))	
Aims and Audience	**What is the aim of the mapping?** Developed by Natural England and CEH to provide publically accessible 'off-the-peg' maps of natural capital in England, without the need for additional data input or modelling. Maps are accessible to view or download as high quality images or GIS layers. Users can take a map away and combine it with other GIS layers, or cut it to the part of the country that they are interested in. Accompanying text is provided that details what the map shows and how it has been produced. **Who is it primarily aimed at?** Conservation practitioners and anyone else with an interest in knowing where natural capital is located. No need for GIS/spatial data/technical skills or time/resources for data input and modelling. Those with basic GIS skills can download compatible layers for use in GIS applications. **What data is used to create the maps?** CEH Countryside Survey Sample data (2007) and Land Cover Map 2007 (Carey *et al.* 2008; Morton *et al.* 2011), plus additional data specified in the report for each map.
Approach	**What method does the model use?** Produced using a range of datasets, including CEH sample data from the Countryside Survey (Carey *et al* 2008). Maps were produced at an England level through statistical interpretation and extrapolation from the sample data. Maps show mean value for a 1 km grid square and standard error from the mean, showing uncertainty. **At what scale can it operate?** Maps are provided at 1 km grid resolution showing mean values for each attribute. They can be used at any scale, above 1 km, however due to the 1 km resolution, they are of less value at a local level. **Are there any important limitations of the mapping?** • Mapping is limited to a suite of maps of ten different aspects of natural capital. • Values for each 1 km square are generated from a statistical model of samples; hence the map does not show direct measurements from each location. • Areas such as urban and littoral rock are not sampled, have no associated data and are shown in white on the maps. • Where sample sizes for particular habitats were insufficient to estimate mean values, these areas are also shown in white on the maps. • The map shows mean values at a 1 km square resolution. The standard error attributed to the mean estimates is only valid at 1 km square resolution. The standard error at different resolutions is unknown.

Coverage	**What habitats, species, ecosystem services, access for people or landscape considerations are covered?** 10 maps of natural capital are provided covering: • Soil carbon • Soil nitrogen • Soil pH • Soil phosphorous • Soil bacteria • Soil Invertebrates • Headwater stream quality • Carbon in vegetation • Nectar plant diversity for bees • Plant indicators for habitats in good condition **What potential exists to expand current coverage?** In future CEH are in a position to produce further maps of natural capital, given funding.
Potential for Combination	**Can the model be used in combination with other models and data?** GIS compatible layers can be downloaded for use in combination with other GIS layers. The website includes a facility for viewing the 10 maps in combination with each other.
Data Requirements	**Are there additional inputs of data required?** No. **What are the time requirements for inputting data?** None
Transparency, interpretability, consideration of uncertainty and quality assurance	**How reliable and understandable are model outputs?** Each map is accompanied by a plain English explanation of how the map has been created and its limitations. Each mean value map is accompanied by an uncertainty map, showing the standard error from the mean. The higher the standard error, the higher the uncertainty.
Intellectual property rights, data access and operating system requirements	**What are the requirements and limitations, in this respect, for using this model?** Map layers are available to download through registering with the CEH Environmental Information Platform (https://eip.ceh.ac.uk/ (Accessed 8/2/19)). High quality images and reports for each map are available to download from the tool. Underlying data, used to produce the maps, is not available to download. The following attribution statement, to acknowledge the source of the information, must always be used: 'Contains data supplied by Natural Environment Research Council.' Copyright notices identified in the metadata record for the Data, must be used on all copies of the Data,

	publications and reports, including but not limited to, use in presentations to any audience. The citation of any relevant key publications and Digital Object Identifiers identified in the metadata record for the Data should be included in full in the reference list of any reports or publications that describe any research in which the Data have been used.
Strengths	**What are the strengths of the maps?** Open access, 'off-the-peg' maps of 10 aspects of natural capital in England, not requiring additional data input or modelling.
Weaknesses	**What are the weaknesses of the mapping?** 1 km resolution; maps from sample data, not direct mapping; urban areas not sampled.
Examples	**Where has the mapping been used and for what?** • Mapping for Natural England & Environment Agency Integrated Area Plans • Natural England natural capital accounting

A4.2.7 Natural Capital Atlases (Wigley *et al.* 2020)	
Aims and Audience	**What is the aim of the mapping?** To provide simple, publically accessible atlases that map the environmental properties (natural capital asset quantity, quality and location) which support the provision of ecosystem services. Ecosystem services are also mapped where possible. The atlases are based on *Natural Capital Indicators: for defining and measuring change in natural capital* (Lusardi *et al*. 2018), which took a systematic approach to identify the properties of the natural environment that underpin the provision of ecosystem services. **Who is it primarily aimed at?** Anyone planning to enhance natural capital and the multiple benefits it provides. No need for GIS/spatial data/technical skills or time/resources for data input and modelling as the maps are pre-prepared and provided in an atlas. **What data has been used to produce the maps?** A wide range of data sources have been used to map the natural capital indicators.
Approach	**What method does the model use?** The atlases map the indicators, and use the data sets, identified in Lusardi *et al.* (2018). This report used logic chains to systematically identify the properties of the natural environment that underpin the provision of ecosystem services. The data sets are processed to present the data as hexagons at different resolutions.

<table>
<tr><td></td><td>At what scale can it operate? Applicable at a national, regional and county/core city scale. Maps are presented using hexagons at 25 km^2 (national atlas) and 5 km^2 (county and core city atlases) resolutions.

Are there any important limitations of the mapping? The indicators mapped are limited by the data available. The resolution limits the use of the maps at a more local scale.</td></tr>
<tr><td>Coverage</td><td>What habitats, species, ecosystem services, access for people or landscape considerations are covered?

A suite of maps of ecosystem asset:

• <u>Quantity</u> – extent of Priority Habitats, marine habitats, urban blue and green space, arable landuse, ponds and woodland (including ancient and coniferous).

• <u>Quality</u>
o Hydrology and geomorphology: e.g. naturalness of flow regime.
o Soil and sediment properties: e.g. carbon, biota.
o Chemical and nutrient status: e.g. nutrient status of soil & water.
o Species composition: e.g. invasive non-native species.
o Vegetation characteristics: e.g. cover, pollinator food plants.
o Cultural: e.g. tranquillity, historical environment, boundary features, Public Rights of Way.

• <u>Location</u> e.g. to mitigate air quality, noise, local temperature.

• <u>Ecosystem Services</u> e.g. water available for abstraction, carbon density in top soil.

What potential exists to expand current coverage? The maps cover the whole of England at a national and county/core city scale. A GIS tool is available to apply the mapping methodology for other boundaries.</td></tr>
<tr><td>Potential for Combination</td><td>Can the model be used in combination with other models and data? Potentially, for example where habitat networks for biodiversity are being planned, these maps could help identify the multiple benefits that could be provided by a place.</td></tr>
<tr><td>Data Requirements</td><td>Are there additional inputs of data required? No, although local data can be added to measure indicators, if a local atlas is being created.

What are the time requirements for inputting data? None unless the data is being cut to a new boundary.</td></tr>
<tr><td>Transparency, interpretability, consideration of uncertainty and quality assurance</td><td>How reliable and understandable are model outputs? Due to the simple methodology, the maps are transparent and easy to interpret. No modelling is undertaken. Data are processed to be presented as hexagons at different resolutions.</td></tr>
</table>

Intellectual property rights, data access and operating system requirements	**What are the requirements and limitations, in this respect, for using this model?** Copyright statements are detailed on each individual map. Maps comply with licensing requirements for their use.
Strengths	**What are the strengths of the maps?** 'Off-the-peg' atlases at national, county and city levels. A systematic integrated framework is used to identify the ecosystem services that the maps underpin. All of the indicators identified in Lusardi *et al.* (2018) are mapped, subject to data availability and licensing. Gaps are identified where indicators are not mapped.
Weaknesses	**What are the weaknesses of the mapping?** Applicable at national, regional and county scales, rather than local.
Examples	**Where has the mapping been used and for what?** A natural capital atlas of the Oxford-Cambridge Arc[40] of economic growth has been produced, using the same methodology at a 1 km resolution, to inform the development of the Local Natural Capital Plan.

A4.3 Decision support tools

A4.3.1 Forest Research least-cost network approach (Watts *et al.* 2010)	
Aims and Audience	**What does the model aim to do?** The least-cost approach can be used to define ecological networks by identifying habitat patches and the potential connectivity between them, taking into account the permeability/resistance of the surrounding landscape matrix. The approach can be used to define discrete ecological networks or to calculate the probability of connectivity between all habitat patches (Watts & Handley 2010). **Who is it primarily aimed at?** Conservation practitioners, land managers, woodland managers, local authorities and others. Users need to have, or have access to, some GIS/spatial data/technical skills. **What decisions does the model best inform?** The least-cost approach can be used to inform the development of nature networks and connectivity, and to evaluate change (see examples in Watts *et al*. 2010).
Approach	**What method does the model use?** The least-cost approach works by defining the habitat for selected focal species and modelling the

[40] https://www.gov.uk/government/publications/the-oxford-cambridge-arc-government-ambition-and-joint-declaration-between-government-and-local-partners

	connectivity based on the species dispersal distance and the impact of the landscape matrix on species movement (Humphrey *et al.* 2005). Particular landscape features may promote movement, such as those which are structurally similar to the home habitat, while others may restrict species movement (Eycott *et al.* 2012). In summary, the network approach creates a buffer around a previously defined habitat patch, this buffer is compressed or stretched by the underlying land cover, a network is defined where these buffers intersect (based on a dispersal distance). **At what scale can it operate?** Least-cost approaches can, and have been, used at multiple scales from local to national.
Coverage	**What habitats, species, ecosystem services, access for people or landscape considerations are covered?** Expert opinion has been collected to parameterise the least-cost approach for the following broad habitats (Eycott *et al.* 2011): • Broadleaved, Mixed and Yew Woodland • Neutral Grassland • Fen, Marsh and Swamp The least-cost approach has also been used for a number of 'generic' and real woodland species (e.g. Stevenson *et al.* 2013) and to model the movement of people in urban environments to access greenspace (Moseley *et al.* 2013). **What potential exists to expand current coverage?** The least-cost approach can be parametrised for any purpose for which you have data or values.
Data Requirements	**Are there additional inputs of data required?** The least-cost approach requires the following data: • Habitat spatial data • Landscape matrix spatial data • Dispersal distance or dispersal kernels • Landscape matrix resistance values There is limited information on dispersal distance or matrix resistance values for many species, as a result expert-opinion has been systematically collected to fill evidence gaps (Eycott *et al.* 2011) along with a number of empirical studies.
Transparency, interpretability, consideration of uncertainty and quality assurance	**How reliable and understandable are model outputs?** Least-cost modelling is a well-established technique in landscape ecology and is reliable and useable within the understanding and caveats of such tools.

	If using the spatial data outputs, GIS skills are required to represent the data correctly. With the appropriate supporting documentation the spatial outputs are easily understood. Input data limitations should be referenced when using outputs, ideally using local knowledge and experience.
Intellectual property rights, data access and operating system requirements	**What are the requirements and limitations, in this respect, for using this model?** The method to define least-cost networks and the connectivity indicator is clearly described in the supporting papers, allowing them to be reconstructed in GIS software. Forest Research has various versions of the network and indicator tool, including a recent version in R.
Strengths	**What are the strengths of the model?** Provides a useful and simple representation of a functionally connected ecological network for selected or generic species, based on a limited number of parameters. Can be used to illustrate gaps in networks, target various conservation actions and to evaluate change.
Weaknesses	**What are the weaknesses of the model?** The least-cost approach provides a simple illustration of connectivity and ecological networks based on a small number of parameters. Empirically derived parameters, especially resistance values, are rarely available for many species, as such there is a heavy reliance on expert opinions. However, there are approaches to gather this information systematically (Eycott *et al.* 2011).
Examples	**Where has the model been used and for what?** Forest Research has used least-cost approaches, and associated tools, in a wide range of situations – see Watts *et al*. (2008) for a general review.

A4.3.2 Condatis http://wordpress.condatis.org.uk/ (Accessed 8/2/19)	
Aims and Audience	**What does the model aim to do?** Condatis is a decision support tool that can help to identify the best locations for habitat creation and restoration to enhance existing habitat networks and increase connectivity across landscapes. **Who is it primarily aimed at?** Conservation practitioners and land use change practitioners e.g. Local Planning Authorities. The users will need to have, or have access to, some GIS/spatial data/technical skills. **What decisions does the model best inform?** An important feature of this tool is its ability to predict patterns of the 'flow' of species through a landscape, highlight where there may be 'bottlenecks' in this flow and evaluate where habitat creation will contribute the most to increasing that flow, or connectivity.
Approach	**What method does the model use?** Condatis uses the example of electrical circuit boards as a way to represent landscapes and model the way a species moves through them. The ability of species to move

	(current) through the landscape (board) varies depending on the configuration of the habitat patches (the wires and resistors). This is a useful tool for representing ecological networks and species movement in response to climate change as it uses a source and destination approach that can replicate the movement of a species across latitudes or altitudes (Hodgson *et al.* 2012). **At what scale can it operate?** Any scale, it has been applied nationally, for example Wales and England, but is probably better applied at a more regional or local level in most circumstances
Coverage	**What habitats, species, ecosystem services, access for people or landscape considerations are covered?** This model focuses on ecological networks/habitats as a means for species to move through the landscape. Whilst there will be multiple benefits by providing extra habitat in locations suggested by this method, the primary consideration is to enable species to use habitat networks. **What potential exists to expand current coverage?** There is the potential to contribute to the further development of Condatis, however, it is most likely that its focus will remain on species movement. The interpretation of the results could be used in combination with other data and tools to contribute to synergistic delivery of ecological networks.
Data Requirements	**Are there additional inputs of data required?** Habitat or land use type spatial data is required in the correct format for use in the model. Some information or thinking about the reproductive rate and dispersal distances, at least for indicative purposes, are also required. **What are the time requirements for inputting data?** The model runs fairly quickly but will require time to prepare the data, make some input decisions then run the model and interpret the results.
Transparency, interpretability, consideration of uncertainty and quality assurance	**How reliable and understandable are model outputs?** The outputs are particular to this model so some understanding of the approach is required to interpret them. The documentation required to understand the results is provided on the Condatis website. As with all tools, the outputs are as reliable as the data put in and where this has flaws (as all data has) they should be understood and referenced when using the outputs. The best way of doing this is interpreting either the inputs and/or outputs using local knowledge and experience.
Intellectual property rights, data access and operating system requirements	**What are the requirements and limitations, in this respect, for using this model?** Condatis an open source program available for anyone to download. It is released under the GNU General Public Licence version 3. The software runs on Windows and Unix-like operating systems such as Mac OS X and Linux and is written in Python 2.7. See website for further details.
Strengths	**What are the strengths of the model?** It provides a useful representation of the flow through a habitat network for a proxy species that can be used to illustrate gaps or blockages in the landscape.

Weaknesses	**What are the weaknesses of the model?** Input data quality (in common with all tools).
Examples	**Where has the model been used and for what?** There are a series of case studies on the Condatis website.

A4.3.3 RangeShifter (Bocedi *et al.* 2014)	
Aims and Audience	**What does the model aim to do?** The model aims to describe how species will spread across a landscape, based on habitat suitability, dispersal ability and various aspects of population dynamics. **Who is it primarily aimed at?** Conservation scientists with a population dynamics background. **What decisions does the model best inform?** It can be used for addressing questions regarding connectivity between isolated breeding populations, rates of range expansion and population persistence in static environments and in environments subject to a changing gradient and/or to environmental stochasticity.
Approach	**What method does the model use?** RangeShifter uses a cell-based (raster) representation of the landscape, which can be based on mutually exclusive habitat classes, habitat proportions within each cell, or an index of habitat quality. Different carrying capacities can be assigned to individual habitat types, and, for the purposes of explicit movement modelling, habitat-dependent dispersal costs (in the same way as are applied in the least-cost path approach) and mortality rates can be specified. A species may be represented by discrete generations (e.g. for butterflies) or as a stage-structured population having overlapping generations (e.g. birds, amphibians, etc.). The level of demographic parameters required is flexible; straightforward assumptions may be applied if demographic parameters are highly uncertain, but complex relationships can be represented (such as density-dependence in development or survival) for well-studied species. For certain types of model, individual-level variability may be incorporated, and evolution of demographic and/or dispersal traits may occur. The three key phases of dispersal, namely emigration, transfer and settlement, are modelled explicitly, and alternative methods (statistical kernels and mechanistic movement models) are provided for representing the transfer phase. **At what scale can it operate?** All spatial scales, depending on the availability of data.

	Are there any important relevant omissions from the model? This is purely an ecological model, aspects such as ecosystem services cannot be included to describe the value of land parcels to society, for example.
Coverage	**What habitats, species, ecosystem services, access for people or landscape considerations are covered?** It covers species and habitats. **What potential exists to expand current coverage?** To adapt it so that gradients in climate can be included, including how population dynamics parameters might change under different climates. To incorporate interspecific interactions, because they are known to influence species persistence locally as well as range dynamics. To incorporate evolutionary processes, which are increasingly recognized as being as important as ecological processes for species' responses to environmental changes.
Potential for Combination	**Can the model be used in combination with other models and data?** Yes, for example an informative use of RangeShifter would be to simulate a number of representative species on a series of landscape scenarios produced by other models (plus the current landscape as a control).
Data Requirements	**Are there additional inputs of data required?** It requires a landcover map or habitat suitability map; dispersal and demographic data. **What are the time requirements for inputting data?** The model runs fairly quickly (order of minutes to hours) once all input data are available. However, as it is a complex model, setting suitable parameter values for a range of representative species and deciding exactly how to represent the landscape (habitat types and resolution) will need to follow an iterative process and require the input and participation of local and species experts.
Transparency, interpretability, consideration of uncertainty and quality assurance	**How reliable and understandable are model outputs?** The outputs are readily understandable, and can produce dynamic representations of how a landscape is colonised over time – showing which sites become colonised and when. Given the stochastic nature of the model, multiple runs need to be completed and mapped outputs show the relative likelihood of any particular habitat patch being colonised after a certain time period.
Intellectual property rights, data access and operating system requirements	**What are the requirements and limitations, in this respect, for using this model?** The model is freely available. It can run on standard Microsoft windows PCs.
Strengths	**What are the strengths of the model?** It much better reflects ecological reality than other least-cost methods for modelling dispersal. It uses an individual-based approach whereby the probabilities of productivity, survival and dispersal are all modelled relative to the landscape and habitat qualities. Thus it doesn't assume all sites and habitats are equal and that population will necessarily persist in a site once colonised.
Weaknesses	**What are the weaknesses of the model?** RangeShifter is challenging to parameterise, because of all the population dynamics (and, if required, genetic) parameters required. It does not yet provide for functional

	relationships between its demographic or dispersal parameters and climate variables, it does not include inter-specific interactions; some users will apply the software, generate and report results without fully understanding the assumptions that they are making as they set up their particular model.
Examples	**Where has the model been used and for what?** It has been used in a number of academic studies to explore subjects such as the factors that affect spread rates across fragmented landscapes (Barros *et al.* 2016); how American Mink have colonised Scotland since 1964 (Fraser *et al.* 2015) and the impact of the removal of non-woodland roadside trees and the effects on wider landscape connectivity (Henry *et al.* 2017).

A4.3.4 National Biodiversity Climate Change Vulnerability Assessment (NBCCVA) (Taylor *et al.* 2014)	
Aims and Audience	**What does the model aim to do?** The NBCCVA was designed by Natural England to provide an assessment of the vulnerability of priority habitats to climate change based on principles of adaptation for biodiversity. It identifies which areas might be vulnerable and which possible interventions could have the biggest impact in increasing resilience to the changing climate. The NBCCVA provides: • A spatially explicit assessment of the relative vulnerability of priority habitats based on established climate change adaptation principles • A suite of map-based GIS outputs at a variety of scales which can be used in targeting action to build biodiversity resilience. • A flexible, GIS based, decision support tool: users can incorporate local datasets & select combinations of adaptation principles. **Who is it primarily aimed at?** Conservation practitioners. The users will need to have, or have access to, some GIS/spatial data/technical skills. **What decisions does the model best inform?** Decisions on which conservation interventions can increase the resilience of habitats in different locations. It can also inform prioritisation of adaptation action, or the development of adaptation strategies for biodiversity.
Approach	**What method does the model use?** Uses a 200m x200m GIS grid model to determine the presence of priority habitats then assess them for their: • **Sensitivity** to climate change; assigning high/medium/low sensitivity to climate change from rules based on expert judgement and scientific literature. • **Adaptive capacity**, based on habitat fragmentation, including aggregation of same habitat and land cover in the surrounding

	landscape; topographic variety across habitats and the wider landscape; and current management applications and condition indicators that address current sources of harm for each habitat. Combination of these produces an overall vulnerability assessment. Key output maps show metric results & relative vulnerability. A **conservation value** metric assigns a relative value to land based on priority habitat alone, in national designations or in international designation (highest). **At what scale can it operate?** Can be applied at national and local levels. **Are there any important relevant omissions from the model?** Species are not represented in this approach.
Coverage	**What habitats, species, ecosystem services, access for people or landscape considerations are covered?** Priority habitats: the primary consideration is nature conservation. **What potential exists to expand current coverage?** Potential for habitats/land uses types to be used as proxies for ecosystem services to assess their vulnerability (yet to be tested). The tool can be applied to cover any geographic area required.
Data Requirements	**Are there additional inputs of data required?** Spatial data on habitat and/or land use type; agri-environment schemes; designations and, water quality are required in the correct format: a module within the tool can be used to transform data to the correct format. Other appropriate spatial data can be used, although metrics used by the tool would need to be reassessed. **What are the time requirements for inputting data?** The model runs quickly: once data is prepared, England scale assessment of all priority habitats runs in around 30mins. There is a requirement for data collation and preparation, to make input decisions then interpret the results.
Transparency, interpretability, consideration of uncertainty and quality assurance	**How reliable and understandable are model outputs?** The 200m presence/absence grid needs to be understood initially. A report and supporting material explain: • How each metric is designed. • GIS exercise to show colours & data breaks/classes of vulnerability scores. • How to change visual display of data, colour or breaks. Data reliability should be understood and referenced when using the outputs, ideally using local knowledge and experience.

Intellectual property rights, data access and operating system requirements	**What are the requirements and limitations, in this respect, for using this model?** Available in ArcGIS format (easily transformed to other GIS formats). Open source program available for Natural England staff and partners. The data is released under the Open Government Licence.
Strengths	**What are the strengths of the model?** • Additional, objective evidence to support decisions. • Coverage at a national scale, or can be run at a local scale. • Credible outputs based on established principles & verified data. • Flexibility to suit local requirements and conditions. • Broad range of datasets. • High quality visual map outputs. • Simple and transparent assessment approach.
Weaknesses	**What are the weaknesses of the model?** • Input data quality (in common with all tools). • Priority habitat focus (but can be changed to other land use types). • National scale approach may mask local issues (local data can be incorporated or national data re-classified for local circumstances).
Examples	**Where has the model been used and for what?** • Part of Countryside Stewardship targeting data • Improvement Programme for England's Natura 2000 Sites (IPENS: Natural England (2015)) assessments of climate change vulnerability and habitat fragmentation within Natura 2000 sites. • Natural England Conservation Strategy, investigative project • Nature Improvement Area habitat fragmentation reporting. • Natural England's Area Team Focus Area work. • Local Authorities and National Parks for example in their green infrastructure strategies or climate change assessments.

A4.3.5 Natural Capital Assessment Gateway https://ecosystemsknowledge.net/natural-capital-assessment-gateway (Accessed 8/2/19)	
Aims and Audience	**What is the aim of the mapping?** The Natural Capital Assessment Gateway brings together information on the growing number of projects in the UK concerned with mapping and assessing natural capital and ecosystem service delivery at the local, regional or national level. It provides an interactive, searchable, map-based facility to explore projects in progress or completed across the UK. **Who is it primarily aimed at?** Conservation practitioners and anyone else with an interest in knowing where ecosystem services have been mapped by local projects. **What data has been used to produce the maps?** Varies between local mapping projects.
Approach	**What method does the model use?** This is a web-based gateway that brings together information and location of natural capital mapping and assessment projects. **Are there any important limitations of the mapping?** Varies between local mapping projects.
Coverage	**What habitats, species, ecosystem services, access for people or landscape considerations are covered?** A range of natural capital and ecosystem services varying between local mapping projects. The natural capital and ecosystem services covered are detailed in the Gateway. **What potential exists to expand current coverage?** New local mapping natural capital and ecosystem services projects can be added by submitting information via link on the gateway.
Potential for Combination	**Can the model be used in combination with other models and data?** Varies between local mapping projects.
Data Requirements	**Are there additional inputs of data required?** No **What are the time requirements for inputting data?** Varies between local mapping projects.
Transparency, interpretability, consideration of uncertainty and quality assurance	**How reliable and understandable are the maps?** Varies between local mapping projects.
Intellectual property rights, data access and operating system requirements	**What are the requirements and limitations, in this respect, for using this model?** Varies between local mapping projects.

Strengths	**What are the strengths of the maps?** Web gateway to access locally available maps and assessments of natural capital and ecosystem services in the UK
Weaknesses	**What are the weaknesses of the mapping?** Varies between local mapping projects.
Examples	**Where has the mapping been used and for what?** Each project, accessible via the gateway, is an example of natural capital assessments and ecosystem services mapping.

A4.4 Systematic Conservation Planning Tools

A4.4.1 Marxan	http://marxan.org/ (Accessed 8/2/19)
Aims and Audience	**What does it aim to do?** Marxan is a tool designed to help decision makers find good solutions to conservation planning problems. Marxan is primarily intended to solve a particular class of reserve design problem known as the 'minimum set problem', where the goal is to achieve some minimum area requirements to conserve a suite of biodiversity features for the smallest possible cost. **Who is it primarily aimed at?** Conservation practitioners who have, or have access to colleagues with, Geographic Information System skills. **What decisions does the model best inform?** Helping to identify the priority locations for conserving biodiversity to meet a set of conservation targets, taking into account other factors, so that an optimal solution can be found. It can also evaluate the efficiency of current protected area networks at conserving biodiversity.
Approach	**What method does it use?** It uses a heuristic (non-exact) algorithm, which is allows the processing of large amounts of data reasonably quickly. Prior to running Marxan, one has to: • Define the planning region • Produce a list of conservation features • Divide the planning regions into planning units, these can be grid squares, hexagons or naturally defined units such as parishes. • Decide how much each planning unit costs (the optimal solution will attempt to minimise costs) • Collate all relevant data into GIS format

	• Identify priorities for conservation – set targets that have to be met (such as % of a certain habitat; population size of a species etc.) Once these are defined, one can run Marxan multiple times to obtain the best solution but also identify which planning units are chosen many times and are thus always important to choose, vs. those that are only chosen sometimes, suggesting some flexibility in planning solutions. There are a number of freely-available user-interfaces that make Marxan easier to use – the most important being CLUZ (Conservation Land Use Zoning) which is an ArcView GIS interface that links to Marxan and is available from - https://anotherbobsmith.wordpress.com/software/cluz/ (Accessed 9/2/19) It allows the user to run Marxan easily and map the results of Marxan runs. It also contains tools to help develop the input files required by Marxan. **At what scale can it operate?** The program can operate at any spatial scale, although this is limited by how finely the landscape is divided into planning units. In general, the planning units should be no finer in resolution than the data for conservation features and no coarser than is realistic for management decisions. There is a limit on the number of planning units that Marxan can handle. This is not, however, a fixed number as it depends also on the number of conservation features you wish to plan for and even to some extent on the power of your computer. Unfortunately there is no good rule of thumb for assessing this number but Marxan can quite comfortably run analyses with 10,000 planning units and 100 conservation features. **Are there any important relevant omissions from the tool?** Marxan operates as part of a planning process and is not designed to act as a stand-alone reserve design solution. Its effectiveness is dependent upon the involvement of people, the adoption of sound ecological principles, the establishment of scientifically defensible conservation goals and targets and the development and inclusion of quality spatial datasets.
Coverage	**What habitats, species, ecosystem services, access for people or landscape considerations are covered?** Anything that can be mapped.
Potential for Combination	**Can the tool be used in combination with other models and data?** Yes – it can accept inputs from any other tools that produce spatially mapped results. It can help inform the planning process that will be based on non-mappable information.
Data Requirements	**Are there additional inputs of data required?** It requires data on all the conservation features that are to be included and shape files of the landscape. **What are the time requirements for inputting data?** While the system is straight forward to use, it will take several days to become familiar with it. Once one has the relevant datasets, these can be

	incorporated in a few hours (allowing for inevitable glitches in the datasets).
Transparency, interpretability, consideration of uncertainty and quality assurance	**How reliable and understandable are model outputs?** The outputs are as reliable as the data that is put into the program. The mapped outputs are intuitively easy to understand. The primary assumptions are: • That the input data is not spatially biased, i.e. that the data was collected in a way that the same features would be found everywhere if they existed there • Marxan does not consider uncertainty in the data. It assumes that all feature representations are true, and that all occurrences of that feature are of equal value.
Intellectual property rights, data access and operating system requirements	**What are the requirements and limitations, in this respect, for using this tool?** Marxan is free software and there are no restrictions on its use. The system requirements for running Marxan are quite modest. Any Microsoft operating system will suffice, even a really old one. As a rule of thumb, if a computer is powerful enough to run commercial GIS software, then it will be more than adequate for running Marxan. The more planning units, conservation features and optional advanced Marxan settings you use, the slower Marxan will run. Of course, the more powerful your computer (MHz and RAM), the faster Marxan will run. Depending on these factors, the time required for Marxan to provide 100 good solutions to you problem can range from minutes to days
Strengths	**What are the strengths of the tool?** The tool is freely available; well documented, is improving all the time, and can be used as a transparent way to illustrate the priority area for biodiversity conservation while demonstrating the trade-offs with other land-use needs from other stakeholders.
Weaknesses	**What are the weaknesses of the tool?** The tool becomes less effective where important datasets are mapped at too large a scale compared to other datasets. Thus the results may not be fine-sale enough. Marxan is unable to integrate temporally dynamic data, so it represents a snapshot in time.
Examples	**Where has the tool been used and for what?** Marxan is the most frequently used conservation planning software and has been applied to hundreds of spatial conservation planning problems around the world. It was used to help plan the Marine Protected Areas around the UK – see Delavenne *et al.* (2012).

A4.4.2 Zonation https://www.syke.fi/en-US/Research__Development/Ecosystem_services/Specialist_work/Zonation_in_Finland/Zonation_software / (Accessed 8/2/19)	
Aims and Audience	**What does the tool aim to do?** Zonation is a decision support tool for conservation planners. It is freely available software that can be used to identify priority areas for Protected Area networks, evaluate existing networks and provide optimal solutions to balance the needs of other landuses. Unlike Marxan (see above) Zonation doesn't require a set of feature targets to be set – it identifies a priority ranking between areas, so all parts of the landscape are ranked according relative importance. **Who is it primarily aimed at?** Conservation practitioners who have, or have access to colleagues with, Geographic Information System skills. **What decisions does the tool best inform?** Helping to identify the priority ranking of areas for conserving biodiversity, taking into account other factors, so that an optimal solution can be found. It can also evaluate the efficiency of current protected area networks at conserving biodiversity.
Approach	**What method does the tool use?** Zonation uses an exact algorithm iteratively removing the grid cell or planning unit that leads to smallest aggregate loss of conservation value, while accounting for total and remaining distributions of features, weights given to features, and feature-specific connectivity. Zonation is deterministic and can operate on very large rasters (up to the order of 100 million elements), and thus requires just one run to produce an output (Marxan is more stochastic and requires numerous runs to converge on the best solution). Users have to create the input datasets in a GIS format; choose how planning units will be weighted according biodiversity value and other factors (such as carbon, agricultural value etc.); choose how connectivity should be accounted for; then the program can be run and outputs reviewed. Zonation can incorporate target setting, like Marxan. **At what scale can it operate?** All spatial scales, depending on the availability of data. **Are there any important relevant omissions from the model?** As for Marxan, Zonation can only be used to inform planning processes, because the outputs are only as good as the data include and there will be other stakeholder issues that need to be considered.
Coverage	**What habitats, species, ecosystem services, access for people or landscape considerations are covered?** Any data that can be mapped can be included.
Potential for Combination	**Can the model be used in combination with other models and data?** Yes – it can accept inputs from any other tools that produce spatially mapped results. It can help inform the planning process that will be based on non-mappable information.

Data Requirements	**Are there additional inputs of data required?** It requires data on all the conservation features that are to be included and shape files of the landscape. **What are the time requirements for inputting data?** While the system is straight forward to use, it will take several days to become familiar with it. Once one has the relevant datasets, these can be incorporated in a few hours (allowing for inevitable glitches in the datasets).
Transparency, interpretability, consideration of uncertainty and quality assurance	**How reliable and understandable are model outputs?** The outputs are as reliable as the data that is put into the program. The mapped outputs are intuitively easy to understand. The primary assumptions are: • That the input data is not spatially biased, i.e. that the data was collected in a way that the same features would be found everywhere if they existed there • Zonation does not consider uncertainty in the data. It assumes that all feature representations are true, and that all occurrences of that feature are of equal value.
Intellectual property rights, data access and operating system requirements	**What are the requirements and limitations, in this respect, for using this model?** Zonation is free software and there are no restrictions on its use. The system requirements for running Zonation are quite modest. Any Microsoft operating system will suffice, and as a rule of thumb, if a computer is powerful enough to run commercial GIS software, then it will be more than adequate for running Zonation. The more planning units, conservation features and optional advanced Zonation settings you have, the slower Zonation will run. Of course, the more powerful your computer (MHz and RAM), the faster Zonation will run.
Strengths	**What are the strengths of the model?** The tool is freely available; well documented, is improving all the time, and can be used as a transparent way to illustrate the priority area for biodiversity conservation while demonstrating the trade-offs with other land-use needs from other stakeholders.
Weaknesses	**What are the weaknesses of the model?** The tool becomes less effective where important datasets are mapped at too large a scale compared to other datasets. Thus the results may not be fine-sale enough. Zonation is unable to integrate temporally dynamic data, so it represents a snapshot in time.
Examples	**Where has the model been used and for what?** Zonation has been used widely for the identification of conservation areas or expansions of protected area networks. See examples on the Zonation website.

Natural England works for people, places and nature to conserve and enhance biodiversity, landscapes and wildlife in rural, urban, coastal and marine areas.

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