Part 1

Background information and key concepts

1 Climate change and the natural environment

Climate change

The evidence that the Earth's climate has changed as a result of human activities has become increasingly clear in recent decades, and there is strong evidence that we can expect further changes over the rest of this century and beyond.

At a global scale, the key reference documents are the reports of the **Intergovernmental Panel on Climate Change** (IPCC). The IPCC was established under the auspices of the United Nations and its reports are the work of thousands of scientists who have contributed as authors, editors and reviewers, ensuring that they present a consensus of the scientific community. A series of comprehensive assessment reports have been published since 1990, covering the physical science basis for climate change, impacts, adaptation and mitigation. The most recent fifth assessment was published in stages in 2013 and 2014. The **IPCC website** provides the entry point to the various fifth assessment reports. Their conclusions on the physical science were summarised in a **Summary for Policy Makers**. The strength of evidence of warming and the role of human activity has increased in each successive IPCC report. The Summary for Policy Makers describes warming of the climate system as "unequivocal", and states that it is "extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century". Further reports on **Impacts, Adaptation and Vulnerability** and **Mitigation**, together with a **Synthesis Report**, were published in 2014.

Within the UK, there has been a series of reports on climate change. The main source of information on past trends and future projections is currently the **UK Climate Projections 2018** (UKCP18), published by the Met Office. An introduction to using the climate projections is provided **here**.

The **fact sheets** and **key results** within UKCP18 are the best way to see projected changes in the UK climate at a national and regional level. UKCP18 provides mapped projections of climate change for climate variables such as temperature and precipitation, both seasonally and annually. Climate projections are available for different greenhouse gas emissions scenarios and for different times periods, and show the spread of possible climatic outcomes based on different probability levels. UKCP18 also provides maps of climate projections for the UK at different levels of **global average temperature rise**. This enables one to see, for example, what a 2 °C global increase, might mean for climate conditions in the UK.

The magnitude of change in climate will be influenced by timescale, the extent to which greenhouse gas emissions are controlled, and the sensitivity of the climate system. When considering adaptation it is a good idea to look at a range of plausible scenarios for the next few decades and the rest of the century, for example comparing changes with a 2 °C average global temperature increase and a 4 °C global increase. This will help identify immediate adaptation needs and the path of longer-term changes which may be needed.

All areas of the UK are projected to get warmer, more so in summer than in winter. Changes in projected summer mean temperatures are greatest in southern England. Overall annual rainfall is not projected to change very much, but it is likely that average winter rainfall will increase and average summer rainfall will decrease. Warmer temperatures in summer months will also drive increased evapotranspiration, enhancing summer drought conditions. There is also likely to be an increase in the proportion of rain falling in heavy storm events. Over time these changes will increase and the magnitude of these changes will be greater with higher global greenhouse gas emissions.

UKCP18 also provides projections of sea level rise, which are larger than in the previous 2009 projections. For London, sea level rise by the end of the century (when compared to 1981-2000), for the low emission scenario is very likely to be in the range 0.29 m to 0.70 m. For a high emission scenario, the range is very likely to be between 0.53 m and 1.15 m. Because of movements in the land (slightly rising in the south and falling in the north), the change is smaller in the north of Britain.

The impacts of climate change on the natural environment

The projected scale and rate of climate change, coupled with existing environmental pressures, has serious implications for the natural environment and the services it provides. Climate affects most areas of life, directly or indirectly, and climate change will have wide-ranging impacts. At a global scale, the reports of **IPCC Working Group II** cover impacts and adaptation. A comprehensive national overview of the key climate change risks to the UK, including the natural environment, is presented in the **UK Climate Change Risk Assessment 2017**.

While the emphasis has generally been on the direct impacts of climate change, the way society responds to climate change will also impact on the natural environment. In some cases, these indirect impacts could be greater than the direct impacts. For example, climate change could affect the amount of land used by agriculture and forestry, the choice of crops grown, and decisions on flood protection. All of these could have implications for the natural environment. Many of these indirect impacts are likely to be subtle and gradual, and will be the result of many individual decisions taken at the local level, but there may also be some larger, step-change adaptation actions and tipping points that affect the natural environment. Many of these impacts are speculative and beyond the scope of the adaptation manual but should be borne in mind when using it.

Flooding on the River Severn at Upton-upon-Severn

The effects of climate change on biodiversity have been the subject of many studies in recent decades, and impacts for some species are well documented. The Living with Environmental Change partnership has produced a **Biodiversity Climate Change Impacts Report Card**. This gives an authoritative, high-level overview of the impacts, underpinned by a series of more in-depth reviews of specific areas. The headline messages are given in Box 1. A more in-depth assessment of the impacts on specific habitats is given in the habitat section of this manual. A similar report card has also been published for **Water**, which will be relevant to wetland habitats and for **Agriculture and Forestry**.

BOX 1

Headline messages from the Biodiversity Climate Change Impacts Report Card

- There is strong evidence that climate change is affecting UK biodiversity. Impacts are expected to increase as the magnitude of climate change increases.
- Many species are occurring further north, including some which have colonised large parts of the UK from continental Europe. There are also examples of shifts to higher altitudes.
- Changes in distributions have differed between species, probably reflecting both intrinsic characteristics and effects of habitat fragmentation in slowing dispersal processes.
- Climate change increases the potential for non-native species introduced by people (including pests and pathogens) to establish and spread.
- There is evidence of evolutionary responses to climate change in some species with short generation times, but many, especially those with low genetic diversity or slow reproduction, are unlikely to be able to adapt fast enough to keep pace with climate change.
- There have been changes in the composition of some plant, microbial and animal communities, consistent with different responses by different species to rising temperatures.
- Species populations and habitats have been affected by year to year variations in rainfall and extreme weather events, particularly droughts. Projected changes in these factors could have a major impact on biodiversity and ecosystems, with significant regional variations.
- Some habitats are particularly sensitive to climate change; the risks are clearest for montane habitats (due to increased temperatures), wetlands (due to changes in water availability) and coastal habitats (due to sea-level rise).
- In recent decades, warmer springs have caused life-cycle events of many species to occur earlier in the season. There is also some evidence of delays in the onset of autumn resulting in a longer growing season.
- Regional differences are apparent in the impact of recent climate change on biodiversity, reflecting different species, climate, soils and patterns of land use and land management.

Physical and biological changes will have inevitable consequences for the landscape and way people perceive, use and appreciate the natural environment. Natural England has **published a series of pilot studies** that assess the range of potential climate change impacts and adaptation opportunities for a number of National Character Areas (NCAs). Climate change may also affect the range of ecosystem services provided by the environment. This is an emerging field, but the **UK National Ecosystem Assessment** provides an overview of the various pressures on ecosystem services, including climate change. This topic is explored further in part 7 of the manual.

2 Principles of climate change adaptation

Introduction

This section introduces climate change adaptation in general terms and provides links to the main evidence and policy documents.

Adaptation is about tackling the vulnerabilities and risks climate change brings and making the most of any opportunities. More formally, adaptation can be defined as the *'adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities'*, (IPCC 4th Assessment report Working Group 2 Glossary).

Adaptation is necessary and relevant to all areas of life. Within the UK, the **National Adaptation Programme** sets out the government's priorities for adaptation across all sectors.

Sustainable adaptation and cross-sectoral working

While the natural environment is the focus of this manual, it cannot be seen in isolation from wider human needs and activities. There is increasing evidence that the natural environment can be managed in ways that will help people adapt to climate change, as well as providing benefits for nature and its conservation. This is sometimes known as ecosystem-based adaptation, and examples include creating wetlands where they can provide a buffer against flooding, and creating green spaces or planting trees in towns to lower the temperature locally (as a result of shading and the cooling effect of water loss from leaves).

The Dartford warbler may benefit from warmer conditions and has already expanded its range from southern England.

On the other hand, it is possible for adaptation in one sector to hinder adaptation in others. For example, hard sea defences designed to reduce coastal flooding may prevent the natural readjustment of the shoreline and lead to a loss of coastal habitats. There are circumstances in which this may have to be accepted, for example to protect coastal towns, but often it will be possible to identify alternatives, using coastal habitats as 'soft' defences that provide adaptation for both people and nature.

The concept of sustainable adaptation provides a useful way of looking at some of the prerequisites for a long-term, integrated approach to adaptation, including the synergies and trade-offs associated with cross-sectoral adaptation. Four principles for sustainable adaptation have been proposed (Macgregor & Cowan 2011):

1. Adaptation should aim to maintain or enhance the environmental, social and economic benefits provided by a system, while accepting and accommodating inevitable changes to it.
2. Adaptation should not solve one problem while creating or worsening others. Action that has multiple benefits and avoids creating negative effects for other people, places and sectors should be prioritised.
3. Adaptation should seek to increase resilience to a wide range of future risks and address all aspects of vulnerability, rather than focusing solely on specific projected climate impacts.
4. Approaches to adaptation should be flexible and not limit future action.

Adaptation options can only be evaluated in this way if the objectives and benefits of conservation action are clearly framed. We need to understand what we are adapting for, as well as the impacts we are adapting to.

An important aspect of sustainable adaptation is identifying action that would maintain or enhance the multiple benefits an area provides to society, by reducing vulnerability to a range of possible consequences of climate change. Climate projections necessarily define a range of potential future climates, and there is considerable uncertainty about the cascade of possible consequences for natural systems. It is usually more appropriate to consider a broad range of likely outcomes, as highly detailed or precise projections risk giving a false level of confidence. The **UK Climate Projections** facilitate this approach.

Adaptive management is a commonly used management concept, not specific to climate change adaptation, and is based on a cycle of action, monitoring, review, and, if necessary, revision of actions. It is especially relevant to climate change adaptation, where the nature of impacts and the effectiveness of adaptation measures will become clearer over time. Effective monitoring of changes in the species, habitats and other features of a place is an essential prerequisite for this approach. Monitoring the effectiveness of interventions is also required.

Timescales

While some adaptation measures, such as changing grassland management, or increasing the capture of winter rain, may take only a few years to implement, others such as creating habitats can take much longer. For example, the RSPB's **Lakenheath Fen** project took around ten years from inception to bitterns becoming established. Other habitats, for example woodland, are likely to take much longer to mature and achieve their desired ecological state. With such long lead-in times for many adaptation measures, it is important to start adaptation now.

Adaptation for the natural environment

The Natural Environment is very sensitive to climate, and although it has a natural capacity for adaptation, the speed and scale of current climate change is too quick for many species to either move or adapt in situ. This is exacerbated by the fragmented and degraded nature of many species' populations and semi-natural habitats in the UK. There has been considerable effort to develop systematic, common approaches to climate change adaptation for biodiversity. Within the UK, two early reports on adaptation proposed general adaptation principles; Conserving biodiversity in a changing climate: guidance on building capacity to adapt, produced by the UK Biodiversity Partnership, and the **England Biodiversity Strategy Climate Change Adaptation Principles**. Approaches to adaptation have also been developed in a number of parallel areas, including geodiversity (e.g. Brown *et al* 2012), **forestry** and the **historic environment**. Our approach draws on these and develops them.

Adaptation in the natural environment can be considered under four key elements:

- Building ecological resilience to the impacts of climate change;
- Preparing for and accommodating inevitable change;
- Valuing the wider adaptation benefits the natural environment can deliver;
- Improving the evidence base.

The following sections expand on these areas.

1 Building ecological resilience to the impacts of climate change

Building resilience is about reducing the adverse impacts of climate change and enabling species, habitats and other environmental features to persist in the face of climate change. There can be significant scope for this. There is evidence that reducing non-climatic sources of pressure or harm, such as pollution or habitat fragmentation, can help to ensure that species' populations are better able to cope with stresses from climate change, and in many cases can be tackled more easily than those caused by climate change. Preventing the introduction of pests, diseases and invasive non-native species will also enhance the resilience of a site to climate change.

Changes in the quantity and quality of water pose one of the most significant threats to many ecosystems, but management of catchments can help to maintain water supply in times of drought, and reduce the risks of flooding in periods of high rainfall. Restoring the hydrology of wetlands, for example by reversing the effects of drainage, is a key step in building resilience.

The specific needs of individual threatened species can be addressed by, for example, improving food supply or creating on-site climate refugia to protect them from weather extremes, thus enabling them to persist for longer in their current locations. An important aspect of resilience is maintaining sufficiently large and robust populations that can survive the impact of extreme climatic events such as droughts and heat waves, which may become more frequent with climate change. Larger populations are also more likely to result in species dispersing to new areas locally and further afield. There are other aspects to resilience. Plants and animals experience climate through their immediate microclimate. This may differ significantly from the climate measured by weather stations. For example, a plant or insect on a north-facing slope or in shaded grassland may be many degrees cooler than

one in full sunlight on a south facing slope. Maintaining environmental heterogeneity by protecting or creating a range of topographic features, soil types and vegetation structures may therefore increase the resilience of conservation sites.

Resilience can be addressed at different spatial scales, which may allow for increased climatic vulnerability in particular places, provided suitable habitats are available elsewhere within a larger, functionally connected, surrounding area. The **Making Space for Nature** report (Lawton *et al* 2010) addressed this, and identified a need for 'more, larger, better and joined up' wildlife sites, which would combine as a coherent and resilient ecological network.

Another aspect of resilience is accepting or even promoting change in one aspect of the environment in order to confer resilience to others. So, for example, where a dominant tree species is vulnerable, diversifying a forest stand or planting different trees in the landscape may enable forest cover and landscape character to remain similar. Accordingly, the first step in considering resilience is determining the target, whether it be a species, habitat or ecosystem, as the actions to promote adaptation are likely to differ according to the objectives. A fuller discussion of the concept of resilience in the context of climate change adaptation for the natural environment is presented by Morecroft *et al* (2012).

2 Preparing for and accommodating inevitable change

While much can be done to reduce the risk of adverse impacts of climate change through building resilience, some change is inevitable, and some may be welcomed. For example, the population and distribution of a rare species struggling to survive at the cold end of its distribution may increase as temperatures rise; as has happened with the Dartford warbler in England (at the same time as it is losing ground rapidly in the hot, southerly end of its European distribution). Accommodating change applies to both the physical and biological environment. Coastal erosion is a natural process, but will be accelerated by rising sea levels and increased storminess. Where it does not conflict with other priorities (particularly the safeguarding of settlements), managed realignment of the coastline may allow natural erosion processes, and so maintain geological features and coastal habitats (which in turn can also provide protection for built infrastructure). Similarly, there is evidence that restoring the natural, slower flow of meandering rivers and allowing water onto flood plains can, in the right places, benefit biodiversity and enhance the landscape, while also helping to manage flood risk for human settlements and developments.

An important aspect of accommodation is facilitating the movement of species populations in response to changing climatic conditions. This applies equally at national, regional and local scales - even down to the scale where the distribution of microclimate suitable for a species may change. Different species have different requirements, but strategies to increase connectivity within the landscape, including creating ecological stepping stones and corridors across otherwise inhospitable countryside, and making the intervening countryside more suitable, are likely to benefit a wide range of species. The translocation of species is a more radical option which is being considered by some conservationists where species are unable to relocate naturally, over relevant timeframes, to new areas of climate suitability. This is likely to be most important for immobile, long-lived species such as trees, but will also be important for many other species where their ability to move with their preferred climate may be constrained. There may also be value in establishing species in a wider range of locations within a local area with a range of microclimates or other local factors.

3 Valuing the wider adaptation benefits the natural environment can deliver

The natural environment, when managed appropriately, can provide opportunities to help society to adapt to climate change, while also benefitting nature. The **National Adaptation Programme** encourages the use of these ecosystem-based approaches to foster adaptation in other sectors wherever possible. Natural Flood Management and using trees to provide shade are well known examples. A review of ecosystem-based adaptation can be found in section 4.

4 Improving the evidence base

The evidence base on climate change and the natural environment has increased dramatically in the last two decades and provides a strong basis for adaptation actions. There remain considerable uncertainties. Better understanding of the processes by which climate change affects the natural environment, including the interactions between species and between organisms and the physical environment, will improve our capacity to anticipate change and to implement effective interventions to reduce adverse impacts. It is also important to monitor changes as they occur and to understand the causes of change. As adaptation measures become more widely implemented or integrated into broader resilience building it will become increasingly important to evaluate their effectiveness.

Moving back the sea wall at Titchwell Marsh RSPB reserve to protect the freshwater reedbeds. As a consequence, some brackish marsh areas once protected by the wall will return to saltmarsh.

3 Assessing vulnerability to climate change

This section provides information on approaches that are being used to assess the vulnerability of conservation areas to climate change, as a precursor to developing an adaptation strategy. It draws on methodologies that have been used by Natural England and the RSPB.

The most frequent starting point for a vulnerability assessment is the conservation objectives for a site and the features or assets that are most highly valued, which could be, for example, a particular species, vegetation type, the visual appearance of the site, or an ecosystem process.

Once identified, the potential impact on these features can be assessed. If conservation interest is focused on high level concerns such as broad ecosystem type, landscape character, or ecosystem processes, it will probably be necessary to identify the individual assets that contribute to those features of interest, and consider how these might be affected by climate change.

Four factors contribute to vulnerability to climate change:

1. The changes in climate, both type and magnitude, that are likely to occur in the local area;
2. The intrinsic sensitivity of the species, ecosystem or other feature of the site to those climatic changes;
3. The site-specific or local area conditions that could make things better or worse (taking account of both direct and indirect impacts);
4. The capacity to manage those conditions.

These four factors and their inter-relationships are illustrated in figures 1 and 2.

1. Changes in the climate that are likely to occur in your region

This information can be obtained from regional climate projections combined with knowledge about how the local area has been affected by weather-related events in the past (for example, what would happen if those previous extreme events become more frequent in the future?). It is important to consider a realistic range of possible future conditions.

In adaptation terminology, this is 'exposure' to climate change.

2. The intrinsic sensitivity of the species, ecosystems and other features on the site to those climatic changes

Certain species and habitats are inherently less tolerant of certain conditions, or less able to recover. Our knowledge about tolerance limits of species and other natural features is far from complete, but much evidence has been built up over recent years. See below for a suggested list of published information sources. Expert judgement is also important here.

In adaptation terminology, this corresponds to 'sensitivity' as well as aspects of inherent natural 'adaptive capacity'

3. Site-specific conditions that could make things better or worse

Different aspects of a site can either reduce or exacerbate the effects of climate change. Some parts of a site might be more susceptible than others to particular changes, such as flooding or drought, or might experience greater temperature fluctuations.

In addition, ecosystems and habitats in good condition are likely to be more resilient or able to accommodate change, while those in poor condition are likely to be less resilient. Similarly, large species' populations are likely to be more resilient than small ones. The presence of other environmental pressures (such as water pollution, water shortage, or invasive species) will exacerbate the impacts of climate change. The ability of individual species to cope with change will depend on the availability of suitable habitat, and how accessible this is if they need to move.

In adaptation terminology, this aspect relates to 'adaptive capacity', as well as influencing the 'exposure' of environmental features of interest.

4. Capacity to manage those conditions

What management options are available, both within the site and beyond its borders? What action has been taken before and with what result?

Management primarily addresses site conditions. The intrinsic sensitivity of features and assets to climate change cannot be changed, although one management decision might be to accept the replacement of sensitive species with ones that can better tolerate new conditions.

In adaptation terminology, this is the human management aspect of 'adaptive capacity'.

Figure 1: Factors to consider when assessing the likelihood of change

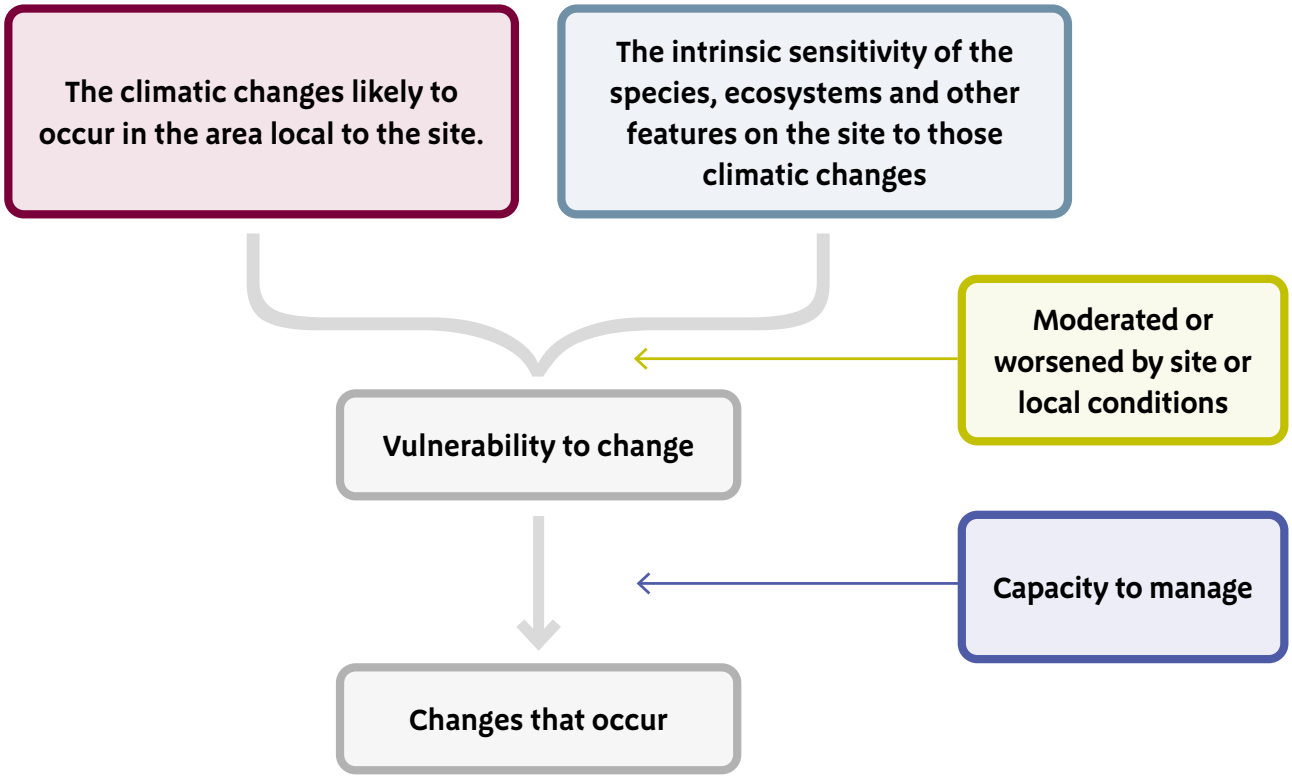


Figure 2: How these four factors determine the likelihood of change

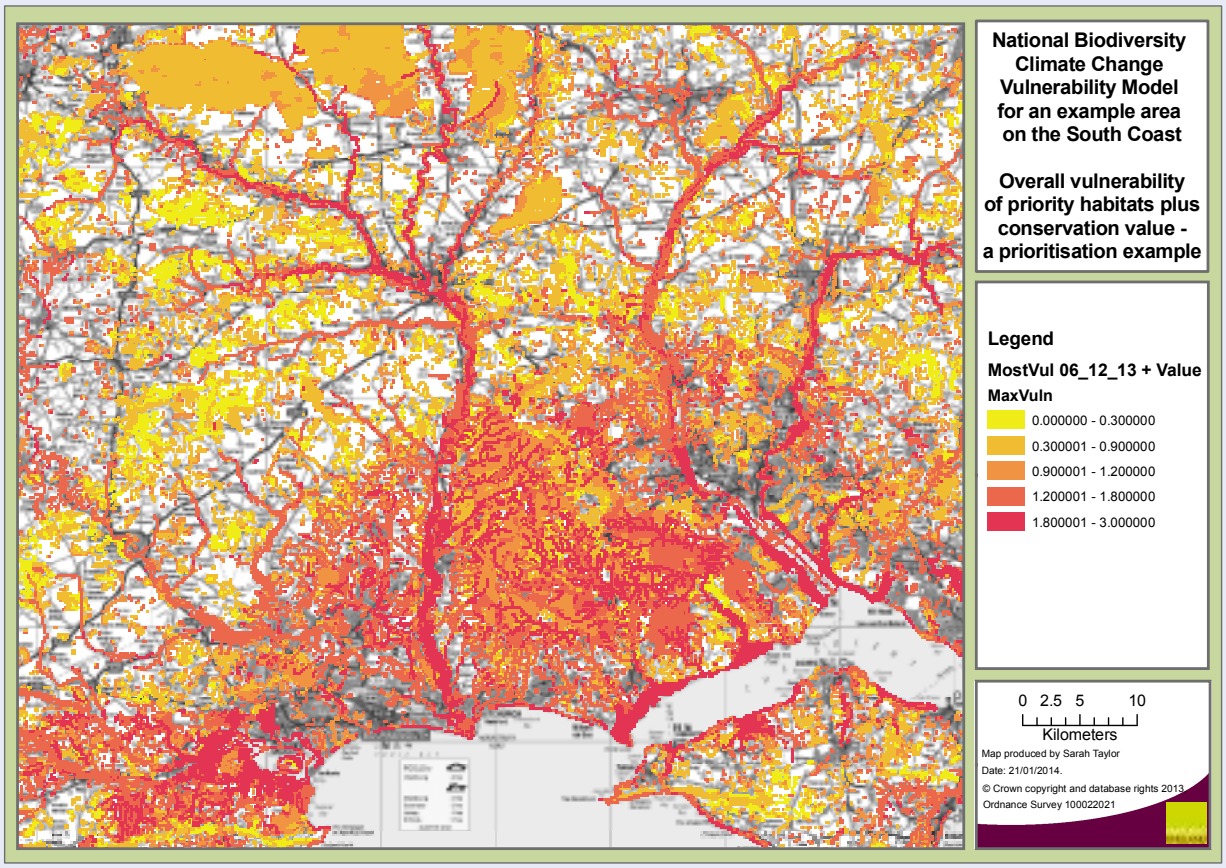
In addition to these four factors, it is worth remembering that:

- Alongside changes to existing site features, climate change can bring new features; for example, new species arriving, or new habitats developing.
- Not only does climate change bring both threats and opportunities, but also the requirement to adapt to make the best for nature and people in an ongoing trajectory of different weather and climate conditions.

BOX 2

Assessing habitat vulnerability at national scale

Natural England has developed a national biodiversity climate change vulnerability model (NBCCVM) to investigate the vulnerability of habitats to climate change. The methodology uses a 200m x 200m GIS grid model to assess habitats for their sensitivity to climate change, their adaptive capacity (including habitat fragmentation, topographic variation and management of current sources of harm to habitats), and their conservation value, reflecting the framework described in figure 2 above. The sensitivity and adaptive capacity elements can be added together to produce an overall assessment of biodiversity climate change vulnerability. Combining this with the conservation value element can be an aid to the prioritisation of action.



The example map above shows the results of the Overall Vulnerability assessment plus Conservation Value, as described above, for an example area on the South Coast. The range of colours represent the range of relative vulnerability to climate change for the most vulnerable habitat overall in that 200m grid square, taking into account the sensitivity, adaptive capacity and conservation value metrics in the model. The red cells are the most vulnerable and the yellow cells are the least vulnerable.

The model can assist prioritisation and planning for biodiversity adaptation, and we expect it to be useful for a range of applications, including ecological network planning, landscape- scale habitat creation and management planning, local development planning, green infrastructure strategies and climate change adaption plans.

Natural England has published a **research report** on the development of the model and the data is available from the **Natural England Open Data Geoportal**.

Please contact **Adaptationmanual@naturalengland.org.uk** for further information.

BOX 3

Assessing vulnerability at the NCA scale

Between 2008 and 2012, Natural England undertook a series of in-depth studies to assess the vulnerability of the natural environment within a range of National Character Areas, and to identify potential adaptation responses. These studies considered the likely impacts of climate change on the most valued assets and features within the NCA, under the headings Habitats and Species, Geology and Soils, Historic Environment, and Recreation. Having assessed these detailed impacts, they then considered how these might combine to affect overall landscape character and the provision of ecosystem services. The methodology used in these studies can be replicated in other areas and can be used at a variety of scales. The reports on the nine of these NCA studies that have been published are available **here**.

Warm, dry conditions will increase the risk of wildfires.

4 Planning site and landscape-scale adaptation

Objective setting

Conservation sites usually have some form of management plan, and adaptation tends to be addressed within this rather than as a topic in its own right. The starting points in this case are the conservation objectives for the site, together with an assessment of the impacts of climate change. Increasingly, conservation is being planned beyond individual site boundaries at a larger 'landscape scale', and climate change is also being factored into some of these initiatives. With both of these scales in mind, adaptation measures and a regular review process should be integrated in site management plans.

A variety of approaches can be taken to building the resilience of sites and populations (see section 2 above) to support present objectives and biodiversity interest. Some of these may simply reflect existing good practice (e.g. reducing other pressures, reducing fragmentation, and buffering sites against surrounding agricultural land). However, these may need to be considered in the context of on-going change to explore the scope for introducing new management responses to meet the same basic objective. At its most straightforward, this may simply be changing the timing of a hay cut to reflect the earlier growth and flowering of plants. It may, however, require more far reaching and resource-intensive measures, for example controlling or blocking drainage channels to maintain the water table in wetlands.

Not all objectives are likely to remain achievable or even desirable as the climate changes, and the extent to which change needs to be accommodated is likely to increase over time. Examples include the changing distribution of species, with some species being lost to sites, and others being gained. In some cases, these changes may simply be accepted and may be positively encouraged as in the case of a rare species colonising a new site. Decisions about when to accept or promote change will need to take account of the wider national or international perspective. Seeking to maintain a population at the southern margin of its range will normally be a lower priority if at the same time it is expanding further north.

Changes to the physical environment can present similar challenges for objective setting. Increased coastal erosion is a particularly serious issue, which can lead to radical changes in habitats and geomorphological features. In these circumstances, the approach will usually be to accept natural processes where this does not threaten human life. This presents a particular challenge for forward planning, in that radical change may happen unpredictably in response to extreme events, such as storm surges. It is nevertheless possible to have contingency plans in place to respond to a range of scenarios, or to plan responses some time in advance of when climate projections suggest they may be needed.

In the case of sites with statutory designations, such as Sites of Special Scientific Interest, there are legal responsibilities associated with maintaining specific interest features, and any threat that climate change poses to these needs to be carefully assessed. Changes to conservation objectives, interest features or site boundaries are possible, and while they are not entered into lightly, Natural England and partners are developing the approach to this. Sites can, of course, acquire new interest features through climate change, as well as losing existing ones, and studies have shown that they are likely to remain important places for wildlife, even though climate change may affect their current interests.

Knowledge and uncertainty

Adaptation often needs to be developed with less knowledge and more uncertainty than is usual when making management decisions. Accepting uncertainty and adopting approaches such as adaptive management to deal with it is widely advocated.

There will always be a level of risk associated with adaptation decisions. For existing habitat, this risk will usually be minimised by adopting 'no-regrets' measures. However, when establishing new habitat, there is potential to look further forward and adopt 'higher risk' measures, including plant species introductions (particularly those with low dispersal potential) than would be appropriate in existing habitat.

Working at the larger scale

Working at larger scales beyond individual sites such as nature reserves has been recognised increasingly as a priority for nature conservation, and this is even more important with climate change. The **Making Space for Nature** review was a landmark in the development of this thinking, and advocated the need for coherent and resilient ecological networks of sites. It defined ecological networks, 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'.*

Some of the key questions to address about protected sites within an ecological network include:

- how many sites are there in the area, and are there any physical or functional relationships between them?
- do existing sites appear to be big enough to cope with more dynamic future conditions?
- how might species move between sites, and are the right sorts of land cover/land management present in the right places to enable this?

The ecological network approach encompasses not just protected sites, but also the wider countryside, much of which is predominantly agricultural in the UK. This is essential to developing climate change adaptation for biodiversity. Recent years have seen the development of landscape scale approaches, such as the RSPB's **Futurescapes** programme, The Wildlife Trusts' **Living Landscapes** approach, and **Nature Improvement Areas**, led by the statutory sector. All these schemes, notably, involve partnerships of different interests, with the potential to make the most of cross-sectoral adaptation to benefit both people and wildlife.

A key aspect of this wider approach is increasing the number of semi-natural habitat patches and making the surrounding farmed landscape more suitable for wildlife, thereby helping species to track their climatic requirements and disperse to new locations. This is described as increasing functional connectivity, and is sometimes expressed in terms of developing corridors or stepping stones. It also helps to reduce the ecological isolation of small fragmented populations, which may be particularly vulnerable to extreme climatic events such as droughts or flooding. Natural England's **Nature Networks Evidence Handbook** (Crick *et al* 2020) contains more information to help design nature networks by identifying the principles of network design and describing the evidence that underpins the desirable features of nature networks. It builds on Making Space for Nature (Lawton *et al* 2010).

Different species have different requirements for movement across the landscape and different capacities for dispersal. Some with limited mobility, such as ancient woodland plant species, will not be able to move fast enough to track projected changes in climate and 'assisted migration' may be the only way to ensure they reach potential new locations. Much of the evidence suggests that even mobile species groups are not currently tracking their climate space (Morecroft and Speakman 2015). Others, such as microorganisms that can disperse on the wind, are less affected by dispersal constraints, provided the prevailing winds are in the right direction. There may also be unwanted consequences of improved connectivity, such as risks from invasive species, pests and diseases. Improving the suitability of the agricultural environment can also help to protect existing biodiverse sites by providing a buffer, and in some cases by effectively increasing their size. These concepts are illustrated in Figure 3 below.

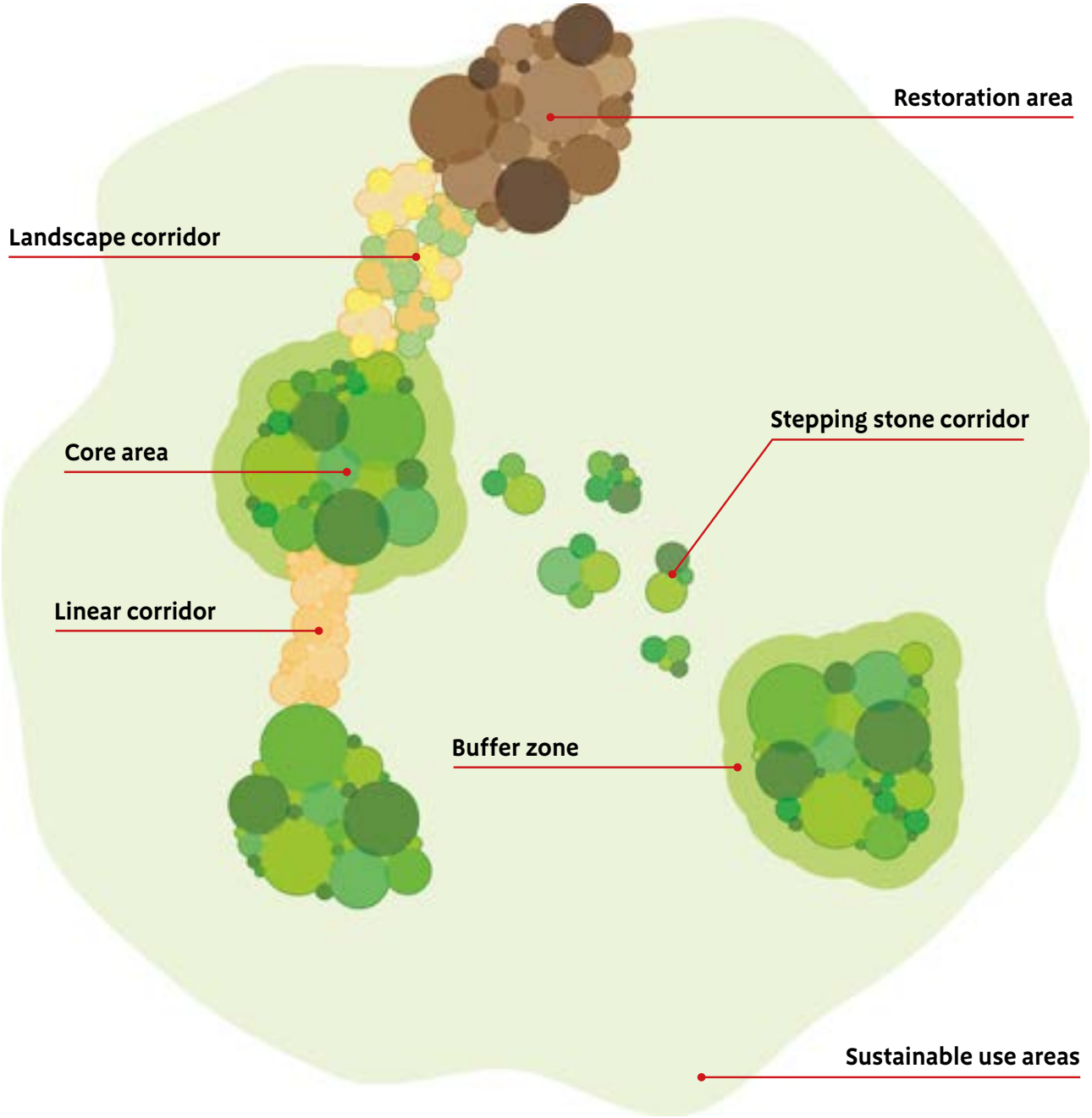


Figure 3: Approaches to improving functional connectivity

Beyond the immediate task of management planning at landscape and site scales, there are a number of wider strategic issues which are better dealt with at national or regional scale. These include:

- At a national level, which species (or other features) are the highest priority for conservation in this area? Is that likely to change as a result of climate change?
- How might new species that may colonise an area (especially invasive and/or non-native ones) interact with existing species, and might they functionally replace existing species that are unlikely to remain?
- Which areas appear to be the most vulnerable, or most resilient, and how do these relate to current sites and the targeting of conservation effort?
- Are adaptation goals and priorities coordinated appropriately across sites, and how do they sit alongside adaptation in the wider landscape?
- Is there replication of types of landscape feature, ecosystems, or species populations, to reduce the risk of losing something completely if one site is lost (for example as the result of a climate-related extreme event), or becomes temporarily degraded? Do new sites need to be created to complement and/or replace old ones?

Adaptation can therefore be looked at from both 'bottom up' and 'top down' perspectives. Figure 4 below summarises the type of questions which are relevant at different scales

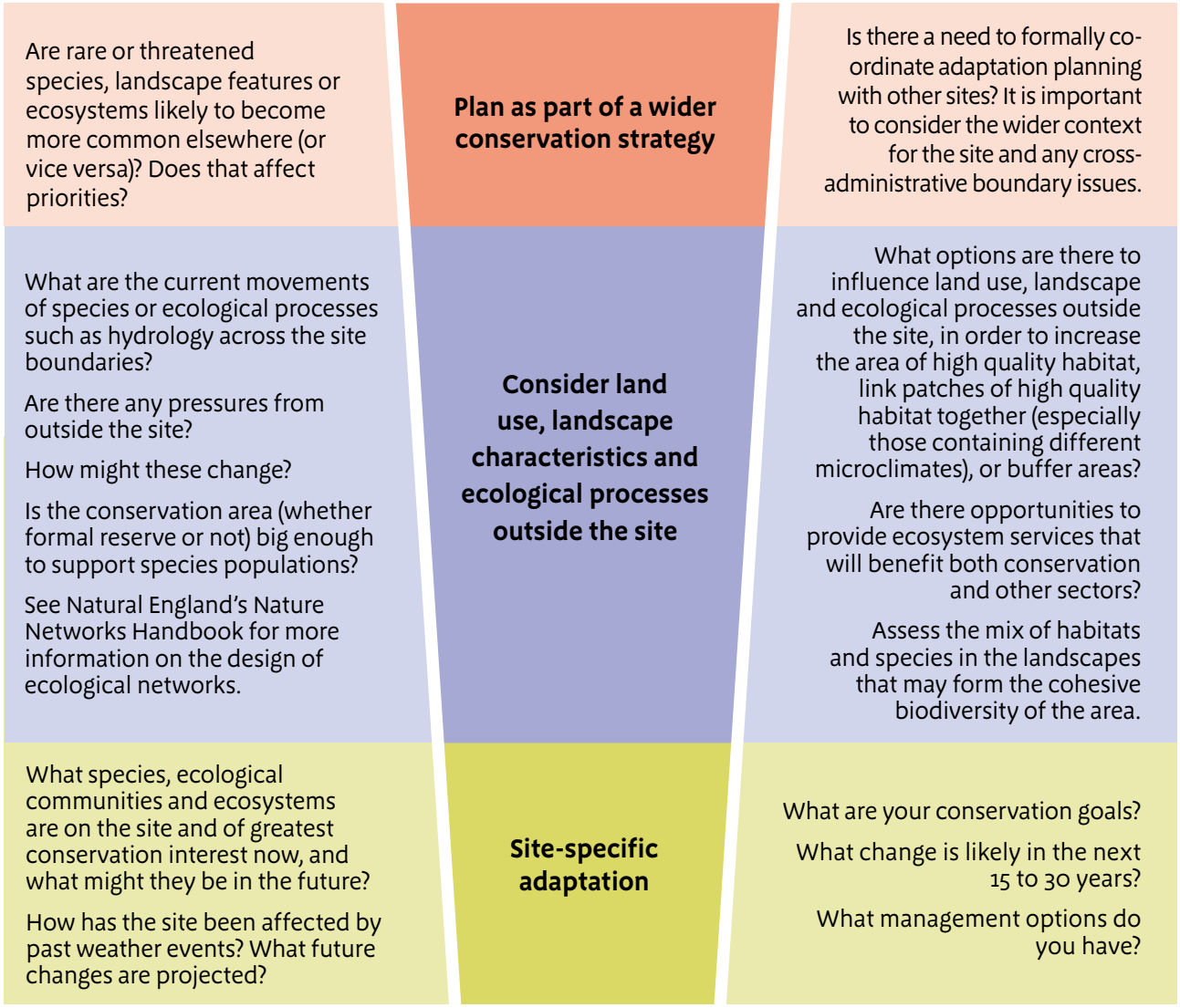


Figure 4: Adaptation questions at different scales

BOX 4

Assessing vulnerability and adaptation planning at the landscape scale

Methods have been developed, by Natural England, the RSPB and others, to assist those wanting to undertake a climate change vulnerability assessment for an area larger than an individual site or specific environmental feature. These methods broadly cover the following steps:

- Identification of interest 'features'
- Identification of climate change variables
- Identification of impacts (direct and indirect)
- Identification of vulnerabilities (and opportunities) of interest 'features'
- Identification of aims and objectives of adaptation action
- Identification of actions
- Monitor and amend actions

These approaches follow a well-known process, an example is detailed by European Climate Adaptation Platform **Climate-ADAPT**. The Natural England approach follows these components and has been adapted from the more in-depth assessment methodology used for the **NCA vulnerability studies** undertaken a few years ago. This streamlined version has been developed to inform landscape scale conservation, but it is intended to be flexible and can be adapted for use in a range of area-wide projects and planning exercises.

The RSPB approach also follows these components, along with an optional workshop format. Logic tables provide a structured framework to work systematically through the key questions of direct impacts, indirect impacts and adaptation responses, along with discussions on related aspects, including communicating the findings.

These are published in appendices to this manual as possible approaches to assessing the possible implications of climate change for an area. Other assessment methodologies and approaches have been developed by other organisations, for example, see the **Broads Authority** web pages for their work on incorporating climate change adaptation in a challenging location.

Please contact **Adaptationmanual@naturalengland.org.uk** for further information.

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