Climate Change Adaptation Manual

Evidence to support nature conservation in a changing climate

2nd edition published 2020

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NATURAL ENGLAND

Climate Change Adaptation Manual

Natural England and the RSPB

with the Environment Agency and the Forestry Commission

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Climate Change Maps produced as part of the *Research on the assessment of risks & opportunities for species in England as a result of climate change (NECR175)* project in the Species section

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- Bees, Wasps and Ants Recording Society
- Botanical Society of Britain and Ireland
- British Bryological Society
- British Dragonfly Society
- British Myriapod and Isopod Group
- Butterfly Conservation (including National Moth Recording Scheme)
- Cranefly Recording Scheme
- Grasshoppers and Related Insects Recording Scheme of Britain and Ireland
- Ground Beetle Recording Scheme
- Hoverfly Recording Scheme
- Longhorn Beetle Recording Scheme
- Soldier Beetles, Jewel Beetles and Glow-worms Recording Scheme
- Spider Recording Scheme
- UK Ladybird Survey

Contact details for all the schemes are available on the BRC website [https://www.brc.ac.uk/recording-schemes].

Bird species distribution maps
Maps and data reproduced with permission of the BTO.

Butterfly species distribution maps
Data from the Butterflies for the New Millennium recording scheme and National Moth Recording Scheme were provided courtesy of Butterfly Conservation. With thanks to Nigel Bourn.

Plant species distribution maps
Maps were provided by the BSBI and are based on records collected mainly by BSBI recorders. With thanks to Kevin Walker, BSBI.

Tree lungwort distribution maps
The maps were provided by the British Lichen Society. With thanks to Janet Simkin.

Baltic sphagnum distribution maps
Maps provided by the British Bryological Society. With thanks to Oliver Pescott.

Dragonfly species distribution maps
Maps were provided by Natural Environment Research Council and British Dragonfly Society. With thanks to David Hepper, British Dragonfly Society.

Mountain bumblebee distribution map
Maps contain BWARS and BBCT BeeWalk data reproduced with permission. With thanks to Richard Comont, Bumblebee Conservation Trust.

Common green grasshopper distribution map
Grasshopper Recording Scheme and National Biodiversity Network. With thanks to Sophia Ratcliffe, NBN and Björn Beckmann, CEH.

Other maps from the NBN
NBN Atlas website at **http://www.nbnatlas.org** Accessed December 2019 and March 2020. Disclaimer - The Data Provider, Original Recorder and the NBN Trust bear no responsibility for any further analysis or interpretation of that material, data and/or information. With thanks to Sophia Ratcliffe.

Foreword

The need for climate change adaptation has become widely recognised in the last 20 years. The environmental sector was one of the first to identify the need and to start developing approaches to adaptation. Initially much of the focus was on identifying general principles. This was an essential first step, but adaptation needs to be embedded into decision-making in specific places and circumstances. There can be a big gap between general principles and specific applications. Effective adaptation requires local knowledge and experience, combined with relevant scientific information and an understanding of practical options. It will be assisted by sharing good practice and evidence of what techniques have worked in particular places and situations.

This Adaptation Manual is a resource to support practical and pragmatic decision-making, by bringing together recent science, experience and case studies, and is intended to be an accessible entry point to a range of available resources and tools. It is not intended to be read from cover to cover: different elements stand alone and can be read individually. We anticipate that the information contained here will be useful to a variety of people, including managers of nature reserves and other protected sites, conservation and land management advisors, and environmental consultants. The intended audience is those who are involved in the management of land for conservation and amenity, and includes staff of local and national government, statutory agencies and NGOs.

The first edition of the Adaptation Manual was published in 2014 and had a focus on habitat management. This new edition updates the information contained in the first edition and has been expanded to include new sections on:

- Species
- Green infrastructure
- Geology and geomorphology, and
- Access and recreation.

Climate change adaptation is a fast moving field and we hope the manual to continue to develop and grow over time.

This manual has been developed jointly by Natural England and the RSPB, with contributions from the Environment Agency and the Forestry Commission.

We welcome feedback and new information from users. Please send any comments to Adaptationmanual@naturalengland.org.uk.

Contents

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 © Natural England/Paul Glendell

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.
© Ben Hall (rspb-images.com)

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. © Andy Hay (rspb-images.com)

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

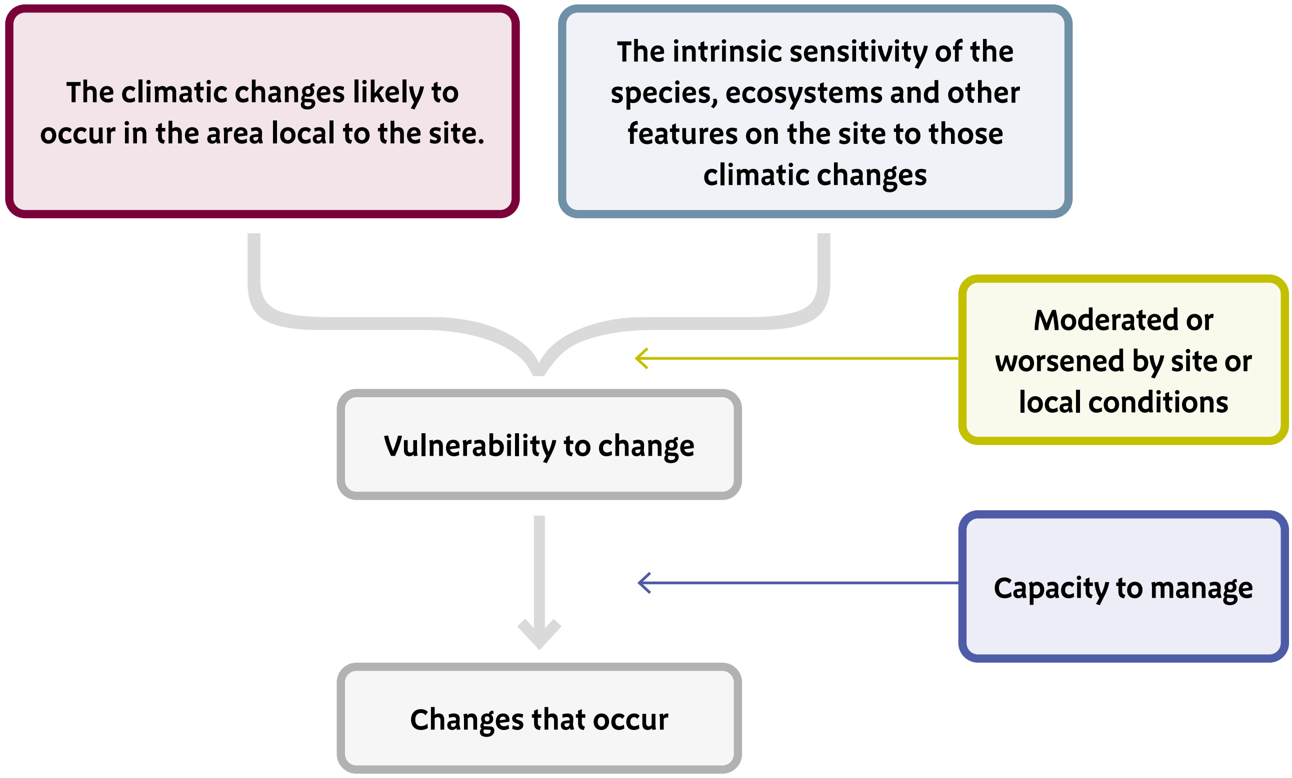


Figure 2: How these four factors determine the likelihood of change

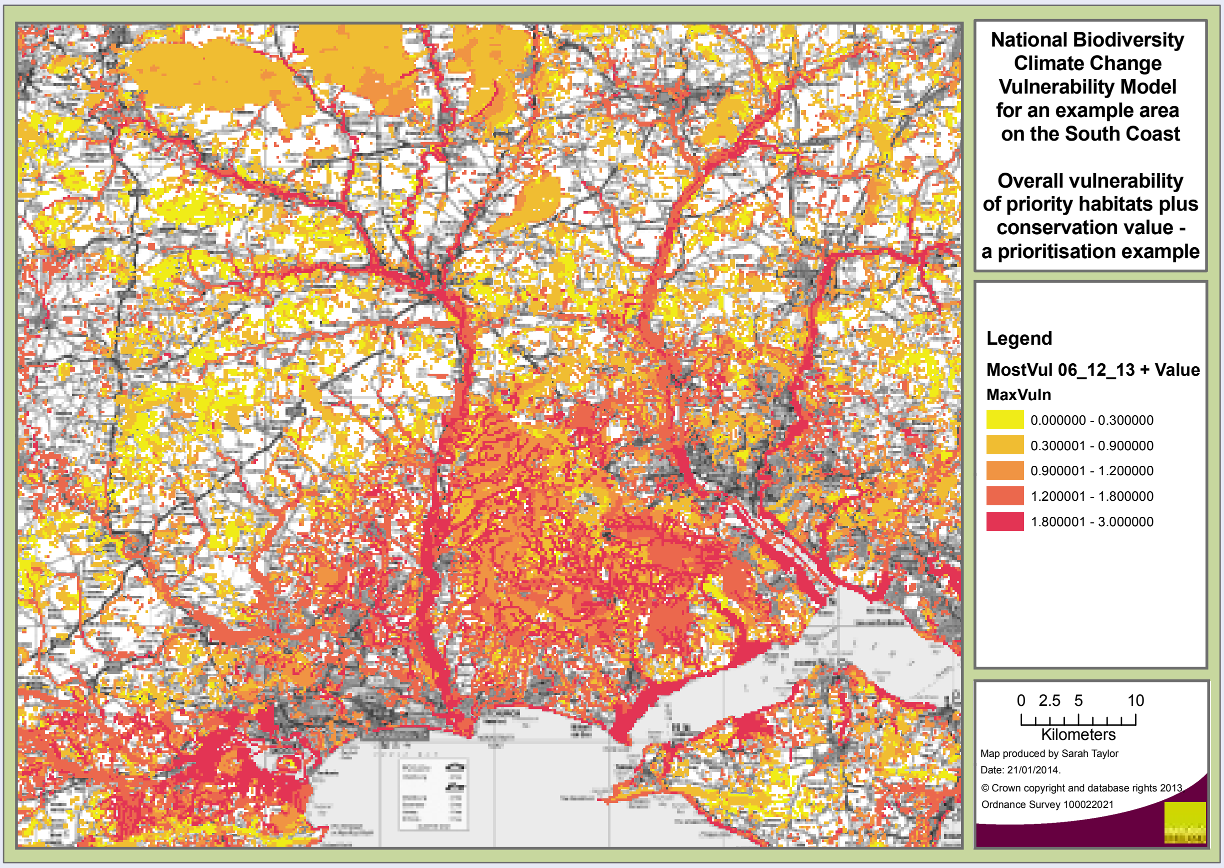
In addition to these four factors, it is worth remembering that:

- 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. © Natural England

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.

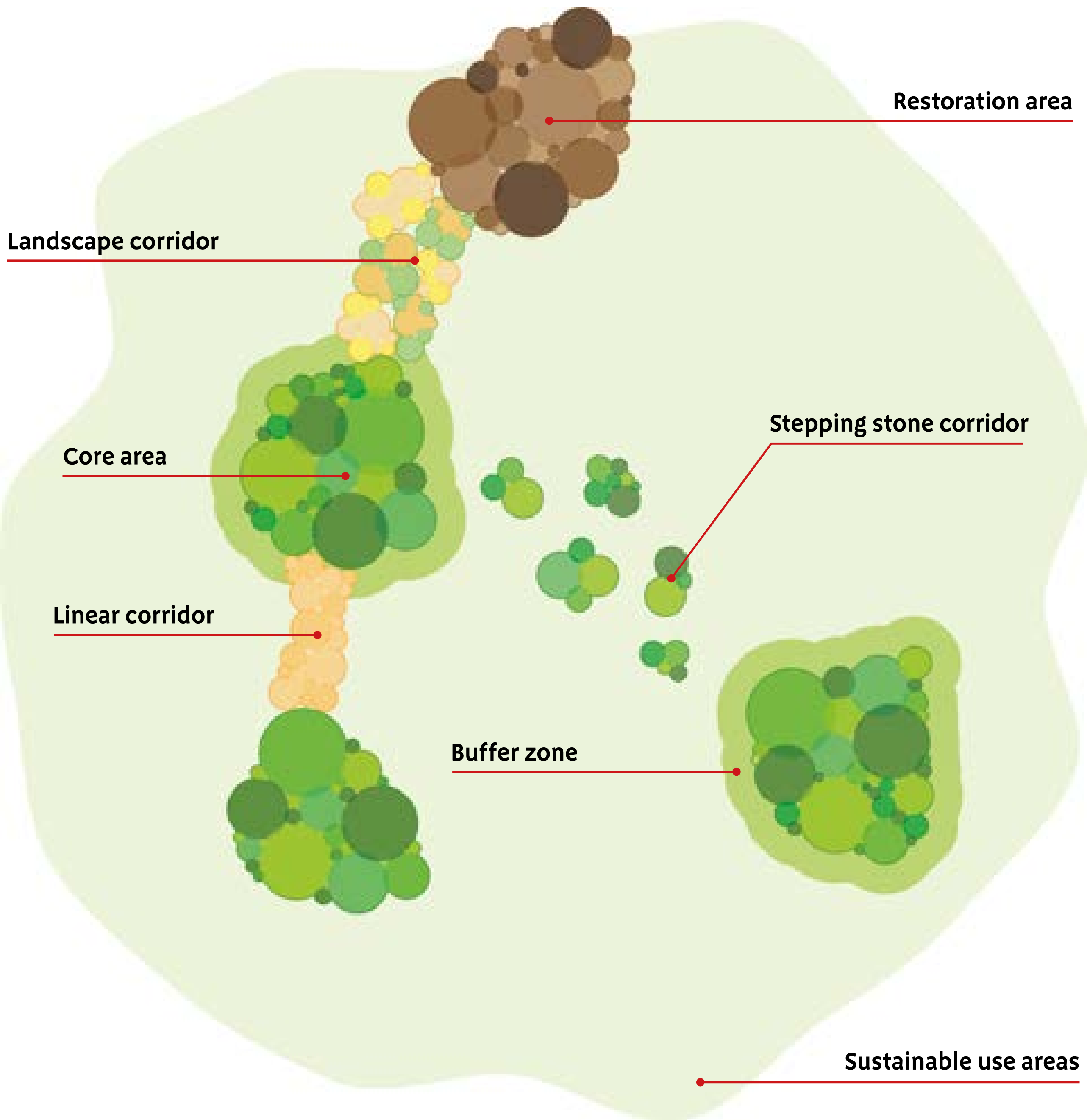


Figure 3: Approaches to improving functional connectivity

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

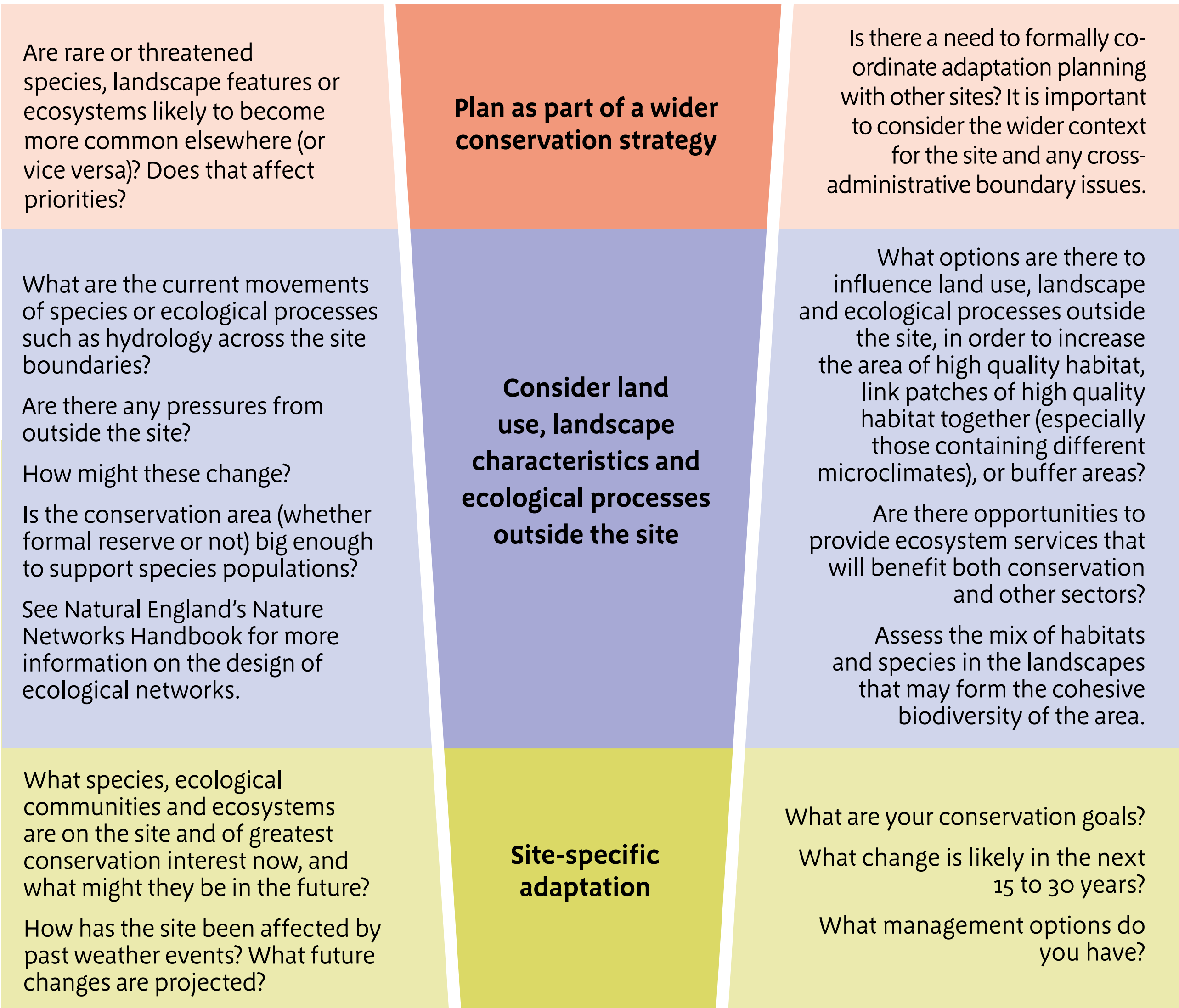


Figure 4: Adaptation questions at different scales

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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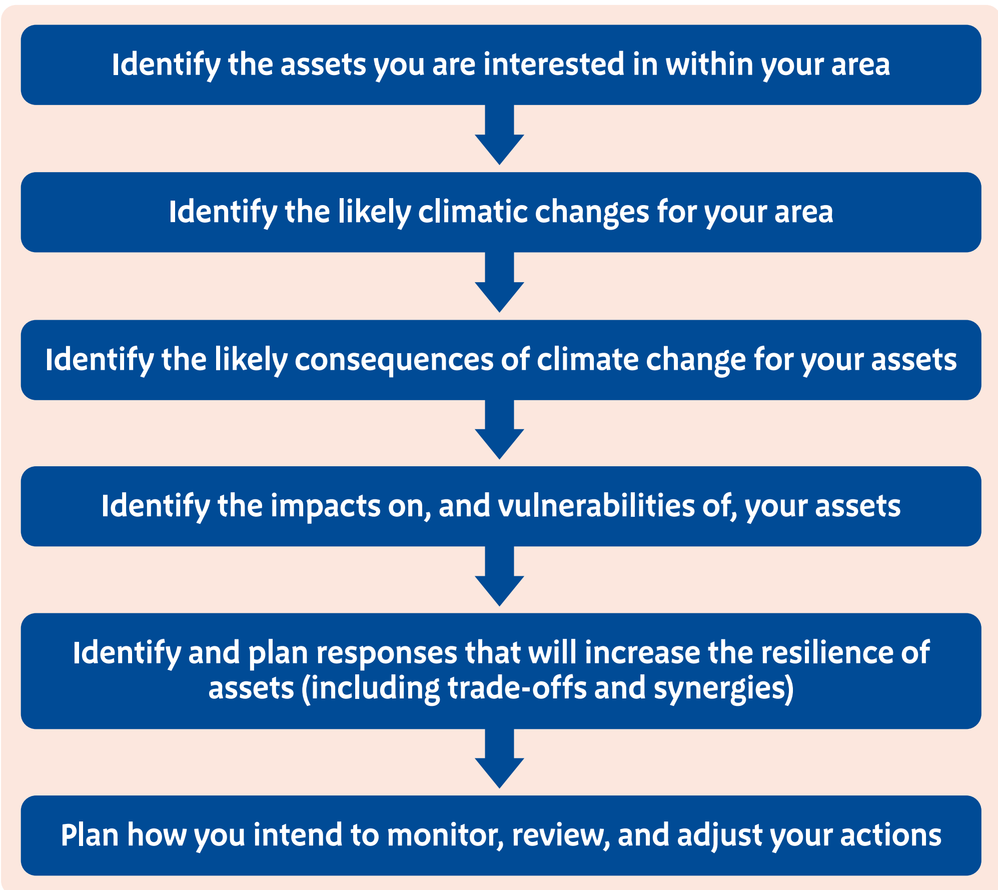
Rockland Broad, Norfolk. © Natural England/Peter Wakely

Annex 1: Natural England's Landscape Scale Climate Change Assessment Methodology

This guidance has been developed by Natural England to assist those wanting to undertake a climate change vulnerability assessment for an area larger than an individual site or specific environmental feature. It is intended to be flexible and can be adapted for use in a range of area-wide projects and planning exercises. It is offered in this manual as just one possible approach to assessing the possible implications of climate change for an area. Other assessment methodologies developed by other organisations are available.

This series of flow charts is designed to help carry out a high level assessment of the impacts of climate change within a project area and to help inform the action that can be taken to address these impacts. Our approach to climate change assessment has been developed over a number of years and has been refined for use in landscape-scale conservation projects. We have also produced and contributed to a wide range of evidence, research, data and analysis that forms the basis of the resources provided to work through the assessment process. The degree of consultation and stakeholder involvement in the process can vary depending on the time and resources available. The overall steps in the assessment are illustrated in simplified form in the flow chart below.

While this approach focuses on identifying vulnerabilities to climate change, it is important to recognise that climate change may have some positive impacts, as described elsewhere in this manual. Where potential benefits or opportunities are identified, these should be recorded in the **impacts and responses table** and reflected in the subsequent action plan.



The following flow charts are provided to guide you through the assessment and to highlight some of the information available to assist with the process.

STEP 1

IDENTIFY the key assets and ecosystem services you are interested in within the project area

By the end of this step you will have identified and, where possible, mapped, the habitats, species and other natural assets that form the building blocks of the area and that you want to assess; and also the ecosystem services provided in the area and their importance to the people that live there.

What are the KEY natural assets identified within the project area?

→ Use existing work in the project area to identify which assets are important within the area. **NCA profiles** may be helpful, as will any relevant protected area management plans, such as for AONBs or National Parks.

You can also note how these assets relate to the delivery of Ecosystem Services, if you have identified these.

Features will include habitats, species, landscape features, historic remains, geological features, ecosystem services, and other natural assets that are important within the project area.

Keep this list relatively short, focus on the most important, indicative or iconic assets in your area.

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Group the KEY natural assets identified for the project area.

→ Group assets by theme, e.g. habitats, species, geology, soils etc. Also identify the ecosystem services provided in and around the project area, in order to identify which assets are important for the delivery of each service.

Grouping them will help make them more manageable to assess and easier to map. Use the impacts and responses template available **here**.

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Map the KEY natural assets identified within the project area.

→ This step will help you to understand what you have and where it is and will relate to actions you will plan in later stages e.g. where to enhance the current ecological network in your area.

These can be existing maps if you have them, or you can use **Magic.Gov** to identify these if you do not have pre-existing asset maps, or request data from the **Natural England Open Data Geoportal**

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MOVE TO STEP 2

STEP 2

IDENTIFY the climate change projections for your area

By the end of this step you will have an understanding of what the latest climate change projections say about changes in climate variables (e.g. temperature and rainfall) in your area. The most up to date projections of climate change in the UK are the **UK Climate Projections 2018** *produced by the Met Office. Links to the UKCP18 key results and factsheets can be found below.*

Have a look at the UKCP18 climate change projections.

→ UKCP18 Factsheets can be found **here**.

UKCP18 Key results can be found **here**.

The UKCP18 home page is **here**.

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Make a note of the projected changes in variables for your area. Log them in your **impacts and responses table**.

→ These projections will help you identify the causes and consequences of the impacts and vulnerability of your assets in the next steps.

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MOVE TO STEP 3

STEP 3

Identify the CAUSES and CONSEQUENCES of climate change on the key assets and ecosystem services identified for your project area

By the end of this step you will have identified the causes and consequences of climate change for the key assets you have identified.

Causes are the climate change variables that will drive change, e.g. drier summers or warmer winters. Consequences are what happens as a result of these changes, e.g. drought or flooding. These will come together to provide indications of the possible impacts on the features identified.

Identify the relevant climate change causes and consequences for each feature.

Causes include - drier summers, hotter summers, warmer winters, wetter winters, increased frequency of storms, high intensity rainfall events, changes in precipitation, increased annual average temperature, reduction in annual average rainfall, sea level rise etc.

Consequences include - drought, flooding, longer growing season, fewer frost events, tidal flooding, saline intrusion, higher storm surge events, reduced soil moisture, waterlogging, erosion, high winds, higher volume of water run-off from land, low water levels/flows, changes in water temperature, higher evapotranspiration rates etc.

This manual will be an important source of information for this step.

The following resources can also provide information:

Natural England's **National Character Area profiles** are a core reference for impacts at a local scale. Natural England has also undertaken more in-depth climate change **vulnerability assessments** for a small number of NCAs.

The **climate change report cards** on biodiversity, the water environment, agriculture and forestry etc. provide the latest overview of impacts across the natural environment.

Record the causes and consequences you have identified for each asset in your **impacts and responses table** (you will use this in steps 4 & 5)

MOVE TO STEP 4

STEP 4

Assess the IMPACTS on, and VULNERABILITIES of, or OPPORTUNITIES for, the key assets and ecosystem services to climate change and other pressures (and interactions between them)

By the end of this step you will have used the information previously gathered on climate change causes and consequences to identify the impacts from these changes on your important features. You will also use your knowledge about the location and condition of the natural assets within your project area to assess how they may be vulnerable to climate change. There may also be opportunities that can be identified.

Vulnerability refers to the ways in which the climate change impacts you have identified could have a negative effect on your asset. For example, increased summer flooding might be an impact and the vulnerability may be that ground nesting bird's nests are vulnerable to destruction. A further vulnerability may be that if the frequency of flooding increases, the success of one or a number of breeding seasons could be reduced over time. Equally, flooding could be an issue in your area but the management of a particular asset may mean that it is not vulnerable to it. This will involve local judgements, informed by guidance on the vulnerability of the features identified to the particular aspect of climate change. The purpose of this assessment is to enable the prioritisation of actions.

Use existing resources to identify climate change impacts on the natural assets you have identified for your project area. Referring to these identified impacts, describe how your assets may be vulnerable to climate change. This could include information on the current state of the asset (if the condition is currently poor the asset may be more vulnerable), the size of habitat/population (smaller may be more vulnerable), heterogeneity (i.e. habitat mosaics), external pressures such as pollution, development nearby, over use etc. Gather extra information and opinions from colleagues and partners, it would be good to reach a consensus on impacts and vulnerabilities.

The following resources can provide information:

- Natural England's **National Character Area profiles** are a core reference for impacts at a local scale. More in-depth vulnerability assessments for selected NCAs are also available.
- The **climate change report cards** (and their source papers) on biodiversity, the water environment, agriculture and forestry etc. provide the latest overview of impacts across the natural environment.
- Subsequent chapters of this manual will contain useful information, particularly the individual habitat sheets and species case studies.
- For information on species, Natural England recently published a **report** on the risk and opportunities for species as a result of climate change. This Manual also includes a section on species.
- Published sources of information should be supplemented by local knowledge and expert judgement, and the assessment should take into account specific local circumstances.

Your conclusions should be entered into the **vulnerability assessment table**.

Review the available spatial data that can help you determine factors that contribute to vulnerability (e.g. condition, habitat fragmentation) and the spatial distribution of vulnerability (or specific adaptation actions in step 5).

Use the suite of climate change related datasets developed by Natural England and others to add a spatial element to your vulnerability assessment. This will help to determine which locations are most vulnerable and where vulnerable assets are located, and help with prioritising adaptation action. Use this **flow chart** to help you incorporate spatial data.

Think also about how climate change impacts could affect ecosystem services, or interact with each other to raise the priority of some issues.

MOVE TO STEP 5

STEP 5

PLAN for integrated action

This step draws together the information gathered previously on impacts and vulnerability in order to plan key actions for the project area. By the end of it you will have developed integrated objectives, prioritised and mapped actions, and agreed how they will be taken forward through a delivery plan.

Identify adaptation actions to address the previously identified impacts and vulnerabilities.

Use the **vulnerability assessment table** to identify appropriate adaptation responses.

This Manual provides more specific information on adaptation options for habitats and species and will form a core resource for planning your adaptation actions.

This **Decision Support Framework** may also help. For non-biodiversity features, the chapters within this manual on geology, access and recreation, and green infrastructure may help, and other organisations such as Historic England have published guidance. In many cases though, combinations of online search and expert judgement may be the best (and only) options.

Think about how you can link adaptation actions to the ecosystem services supplied in the area.

Detail how delivery might reduce the vulnerabilities of assets and services within the project area and how delivery of integrated actions will achieve climate change adaptation and mitigation objectives.

Integrated adaptation, including integrating with our partners, will start out as individual adaptation ideas. When you have a long list you need to cross check the actions for any win-win/no regrets actions or unintended impacts, trade-offs, win-lose issues etc.

Consider having a workshop or meeting session to develop integrated actions.

If possible, invite partners so they can jointly identify existing and planned action and to ensure all partners key objectives are included.

Plan spatial action through use of spatial data.

For biodiversity, use the Lawton Principles (Bigger, Better, More, Joined Up) to help with planning to reduce vulnerability. Resources that may help with this include:

- Natural England's **Nature Networks Evidence Handbook**,
- the **WrEN** project on woodland creation and ecological networks,
- the **GREEN** project on invertebrate colonisation of arable reversion sites,
- Natural England's **research report** on evaluating landscape connectivity and the risks from invasive species.

Link your adaptation actions to other targets, e.g. delivering habitat creation and ecosystem restoration can contribute to biodiversity targets and the 25 Year Environment Plan.

Investigate how the available data can help determine where actions are most needed or may be most effective. This **flow chart** will help you to use the available spatial data.

Agree an integrated delivery plan for the key landscape scale project area objectives.

Provide detail on what successful delivery of actions would be and how this is determined.

MOVE TO STEP 6

STEP 6

DELIVER, COMMUNICATE, MONITOR and ADJUST

This step allows you to explore how you will monitor and periodically adjust your adaptation actions. Early thinking on what can be done to monitor intended delivery outcomes is crucial to allow you to determine success and identify any adjustments required.

Plan how your adaptation actions will be delivered in line with the impacts and vulnerabilities identified, and how they will be monitored and reviewed, and if necessary adjusted, to maximise their effectiveness over time.

Consider the following:

- What are the key indicators that will determine successful adaptation?
- Are there useful monitoring procedures already in place that you can make use of?
- Are the right partners involved?

We understand not all project areas will have an established delivery plan. The completion of this adaptation assessment can help provide an action plan for the area.

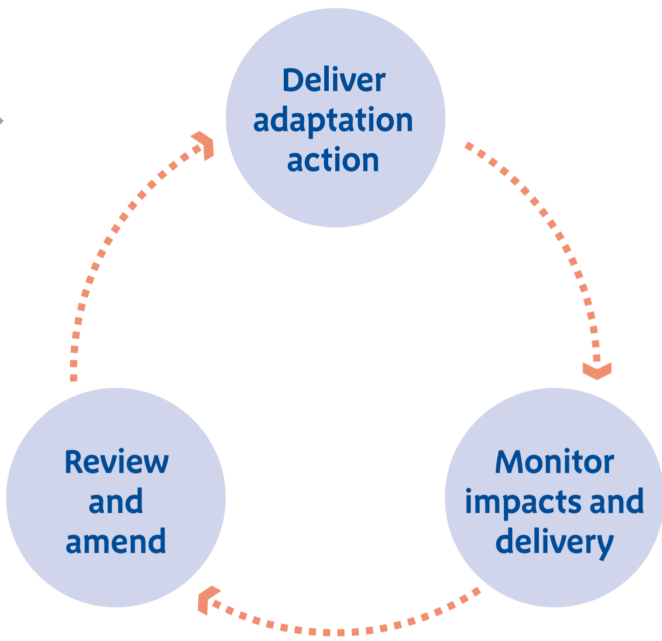
Set a schedule for reviewing the impacts of climate change and the effectiveness of these adaptation actions. Include these commitments in your plan.

You should be prepared to amend adaptation actions if they are not working.

Where possible, ensure that any monitoring or spatial data produced feeds back in to data held by Natural England and others and into the further development of climate change adaptation planning. For example, you could get in touch with Natural England via the **Open Data Portal**.

Integrate climate change action in to existing plans, programmes and partnerships.

Communicate your plan to all relevant partners, especially if they have not been involved in the process. Join up and support will make your plan more likely to succeed.



FINAL ACTIVITY

You could write a short summary narrative of the climate change understanding you have developed for your area to share with your team, organisation or partners, which can be used elsewhere and incorporated into other documents and plans affecting the project area.

Natural England's Landscape Scale Climate Change Assessment Methodology Annex 1:

Impacts and responses table

Asset	The cause – the change in climate variable	The consequences of climate change in relation to the climate variable	Potential impacts and vulnerabilities - Direct or Indirect	Adaptation response
The habitats, species, ecosystem services, other natural assets etc. that are most important to your area. *Keep this list relatively short, focus on the most important/ indicative/iconic assets in your area.*	*E.g. drier summers, hotter summers, warmer winters, wetter winters, increased frequency of storms, high intensity rainfall events, changes in precipitation, increased annual average temperature, reduction in annual average rainfall, sea level rise…*	*E.g. drought, flooding, longer growing season, fewer frost events, tidal flooding, saline intrusion, higher storm surge events, reduced soil moisture, waterlogging, erosion, high winds, higher volume of land run-off, low water levels/flows, changes in water temperature, higher evapotranspiration rates…*	*Identify direct impacts from climate change on your asset. E.g. if salt marsh is an asset in your area, the 'roll back' of this habitat over habitats that exist behind it may be a direct impact of sea level rise.* *Identify all the indirect impacts from climate change on your asset. E.g. if the 'roll back' of this habitat as a response to sea level rise is impeded by coastal defences, the loss of this habitat due to coastal squeeze would be an indirect impact.* *Identify all direct and indirect impacts on your assets* **NB – if you don't have time to list specific vulnerabilities a High, Medium or Low ranking can be used to carry out a 'fast track' assessment.**	*Identify the adaptation responses you need to make to address the vulnerabilities identified. E.g. for the salt marsh example - allow for realignment of shorelines and adequate space and sediment for shoreline adjustment through strategic coastal planning.*

Natural England's Landscape Scale Climate Change Assessment Methodology Annex 2:

Spatial data use

The use of spatial data will enhance the assessment for your project area. It can supplement the stages on assessing vulnerability and planning adaptation by highlighting the spatial distribution of factors that might increase vulnerability to climate change, and also attributes to be protected and enhanced. Please see **Natural England's Nature Networks Handbook** *for more information on how to plan ecological networks. Chapter 4 of the Handbook gives an introduction to some of the available data and tools. Contact* **Adaptationmanual@naturalengland.org.uk** *for further information. The following chart gives some examples of Natural England datasets and how they can help you plan spatially in your area.*

National Biodiversity Climate Change Vulnerability Assessment data and tool.

→ **ASSESSING CURRENT VULNERABILITY** – this data will provide you with information on a series of metrics that describe some elements of how habitats will be vulnerable – sensitivity to direct climate change impacts, habitat fragmentation, topographic variety and current management and condition. There is also a tool to allow different assessments to be carried out.

Natural England's National Habitat Network

Carbon storage & sequestration data

→ **POTENTIAL ENHANCEMENTS** – Natural England's National Habitat Network data show where there are opportunities for habitat creation and restoration in close proximity to existing habitat (request from Natural England Open Geodata Portal).

If you have datasets for carbon storage and sequestration they can help identify synergies for ecosystem services.

Climate change refugia data

→ **NEEDS PROTECTION** – this data highlights areas that may provide refugia for species in a changing climate (where they may continue to persist for longest). These areas could receive enhanced levels of protection under a climate change action plan.

Species risks and opportunities data

→ **POTENTIAL ENHANCEMENTS** – these maps may help you see how species may want to move through the landscape and could help identify areas for key ecological network enhancements for key species.

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OTHER TOOLS – there are a number of other tools out there that could be useful. Natural England has worked with the University of Liverpool on the **CONDATIS** tool which you may want to use. There are other tools available for you to explore, please see **Natural England's Nature Networks Handbook** for more information.

Find useful spatial data at **Magic.Gov** or request data from the **Natural England Open Data Geoportal**

Annex 2: RSPB Adaptation Assessment: a framework for embedding climate change into nature conservation

Introduction

Nature is responding to climate change. It's well catalogued - in **LWEC's 2015 biodiversity and climate change report card**, for example. This gives us two key questions – how will our nature conservation interests be affected by climate change, and what should we do in response?

To answer these questions, and start to embed climate change in our conservation work, the RSPB has developed a framework for assessing adaptation needs. This is straightforward to use, requires only a little climate change knowledge and, if undertaken for several areas of work, provides clear, consistent outputs that build to form an organisation's adaptation programme. It's framed around eight steps, with a workshop structured to bring people together to discuss the implications, and to complete four output tables which capture the thinking and results of the structured discussions.

Our adaptation assessment tool can be used with any level of data and information. We've used the tool principally at a more generic level with largely qualitative information. It doesn't require GIS and electronic datasets, yet these can be used in the analysis. The tool offers a methodology towards embedding climate change as an ongoing element of work programmes, rather than to produce one-off climate change reports. We've taken this approach because we now have to live with ongoing change, with considerable uncertainty about impacts and responses – we'll need to keep thinking about, and re-appraising, climate impacts throughout our working lives.

We've used this adaptation assessment framework across our Futurescape landscape partnerships – and also for other interests, including policy and nature reserves. It's widely applicable, practical and effective – so we are keen for its wider use among conservation partners.

Eight steps to adaptation

There's a logical sequence of eight steps to plan and implement adaptation:

1. Identify your broad objectives / activities / operations
2. Find out how climatic conditions, relevant to your activities, are expected to change
3. Consider how climate change may affect your objectives / activities / operations – from both direct, and indirect, impacts
4. Prioritise the key threats and opportunities from climate change
5. Explore actions to address the impacts of climate change on your objectives / activities / operations
6. Decide what actions should be taken and revise operational activities accordingly
7. Monitor and review effectiveness of action, progress of climate change, achievement of objectives
8. Communication – internal and external, spread best practice

We developed a workshop structure to guide discussion through these steps, with most of the time focussed on the impacts and adaptation actions. This workbook covers the practical organisation and techniques for running of the workshops, for example the 'carousel' method of circulating groups around all the topics for all the key discussions.

We've also developed four fill-in tables to guide and record the discussions and to ensure the required information is captured from the workshops in a consistent way.

Each of the steps is now explored in further detail below.

Step 1 Identify your objectives / activities / operations

What is the aim of this?

- To identify the range of your activities that climate change will affect

List the areas of your work and assess whether they may be affected by climate.

This may be wider than you first imagine. Examples include: managing site a, b, c for specific interests x, y, z; producing a spatial plan for an area; devising a species recovery plan; advising farmers on an agri-environment scheme; ecological research for species p; advising on a proposal for a new development; advocating for water policy; selecting species and provenance for habitat creation; acquiring a landholding; or preparing a strategic work plan.

Step 2 find out how climatic conditions, relevant to your activities, are expected to change

What is the aim of this?

- To get a broad-brush understanding of how climate is expected to change, relevant to your activities

The first step is to gain a descriptive overview of the expected regional / local climate for your interests, for a 2°C average global increase in temperature (the '2°C world'), which is projected to be with us in around 25 years.

Focusing adaptation on the 2°C world has several benefits. It links with the mitigation and political worlds, where 2°C is the widely, politically accepted 'safe' limit of global temperature increase, to which the world's governments are agreed to limiting climate change. It provides a realistic medium term planning horizon. We know we will reach this level of climate change – we can accommodate changes to our plans for this world sooner or later, as time passes. It does away with the need to understand emissions scenarios and simplifies the climatic projections required to understand the future.

The 2°C world is nonetheless most likely a milestone, and not an endpoint: climate change will be with us for centuries, if not millennia. It's also therefore useful to spend some time assessing a 4°C world, for potential long term planning – worst case scenarios have us reaching this in the last quarter of this century. It's also a world we'd best avoid - so learning about a 4°C world may help to bring action on climate change mitigation.

What resources should I use?

- The Met Office Hadley Centre produces climate change projections for the UK – the latest, called UKCP09, were completed in 2009. These include projections based on global average temperature change, at 25 km resolution for key aspects of climate at 2°C, 3°C and 4°C worlds. It's important to use the range of conditions projected by the Met Office – the 10% and 90% probability levels describe the likely range for each variable.
- EA, SEPA: changes to river flows, sea level rise, flooding: mapped projections to be made available via the Intranet, if possible
- Marine Climate Change Impacts Partnership: Annual Report Cards on marine climate change and special topic reports; hub for coastal and marine interests
- IPCC AR5 reports provide the authoritative, global perspective summarising the science of climate change, impacts and adaptation

How should I organise the information?

This Table captures info from Step 2. Start with CC projections for 2°C average global temperature increase and expect these conditions from around 2035-2045. Under current emissions trends, we may expect 3°C average global temperature increase from 2065-2075 and 4°C potentially from around 2090. As our knowledge of climate change increases these timings may change.

Use the 10% and 90% probability levels in the UKCP09 projections to define the range of expected change.

Table 1: Projected climate change relevant to <*name work area*>:

	Mean global temp increase	spring	summer	autumn	winter	Annual
Temperature	*2°C*	*1.5 - 2.5 °C*	*2 – 3 °C*	*2°C*	*0.5 – 1.5 °C*	*1.5 – 2.5 °C*
	3°C		-	-		
	4°C		-	-		
Precipitation	*2°C*	*+ 10 - 20%*	*- 15-25%*	*- 10 to +10%*	*+10-25%*	*-5 to +5%*
	3°C					
	4°C					
Other e.g. SLR, growing degree days etc.						

For some work areas, it may be helpful to use more than one table – for instance, to cover different geographical areas for a national policy interest.

Step 3 Consider how climate change may affect your objectives / activities / operations

What is the aim of this?

- To understand how your key interests, objectives, activities are likely to be affected by climate change

This brings together Steps 1 and 2 in a qualitative assessment of how the changed climatic conditions of a 2°C world might affect your specific activities. You may wish to include potential impacts of extreme weather events in your assessment of climate change impacts. There is however little specific information on predicting extreme events, other than they are expected to become more common in the future. At this stage, restrict this assessment to a short descriptive overview of a few words– e.g. medium level water shortage expected in summer; high risk of sea level inundation; concerns about soil desiccation and animal heat stress; area of proposed development likely to be in only remaining regional wetland; etc.

The impact of climate change may have is assessed by combining the amount of exposure, and the degree of sensitivity, to new / projected climate conditions. Sensitivity may be due both to direct climate conditions, e.g. drying soil or hotter summer temperatures, and to a range of other factors, such as isolated or populations, reduced productivity, species interdependencies, etc. The impacts of climate change may have either negative or positive outcomes.

This step is split into two parts: the direct impacts and indirect impacts of changed climatic conditions:

- Direct impact: e.g. higher summer temperature, greater spring rainfall, increased storminess, longer growing season etc.
- Indirect consequences, from the effect of climate change's impacts on other associations / activities / operations that influence your activities /operations / objectives. The most common types of indirect are those form other sectoral interests - e.g. how changes in farming, water supply, development etc. will impact the conservation interest.

This stage is likely to identify areas requiring further investigation and research to better understand the impacts of future climate.

Resources

Discussion / consideration of the results from Step 2: mix of local knowledge, common sense and scientific studies

- Climate envelope modelling may help guide biodiversity changes associated with future climates
  - Guidance about using climate envelope modelling
  - Climatic Atlas of European Breeding Birds
  - Other species studies: e.g. European butterflies, MONARCH, BRANCH etc.
- The Natural England/RSPB Adaptation Manual provides impacts on both impacts and adaptation
- Site based studies: European IBAs, African IBAs etc.

- Scientific studies – a literature search may be appropriate for your interests
- National studies: e.g. the UK Climate Change Risk Assessment
- Relevant public sector bodies: EA, SEPA, regional climate change groups
- Relevant professional bodies – many will have taken steps to understand the impact of climate change on their sector / interest
- Local / regional CC studies / groups

How should I organise the information?

Two tables have been developed to guide through a step by step assessment and encourage consistency in assessments across the RSPB. One table records direct impacts, the other indirect impacts from likely adaptation or changes in other activities likely to influence our objectives.   This split is important to explore origins and types of impact and to help target adaptation actions.

Table 2: Direct impacts of climate change to <*name work area*>:

Work objective	Key climate change impact	Consequences of changed climatic conditions	Impact on objectives: Threats and opportunities	Level of impact	Timescale of impact
Breeding waders on Sussex lowland wet grassland	*Hotter drier summers*	*Lowered summer water table* *Fire risk increases* *Early / longer growing*	*Hard dry ground for breeding waders June-July* *Destruction of habitat* *Sward too dense for breeding*	*Med* *Med* *High*	*5-10 years* *From 2015* *From 2025*
Pest and diseases	*Milder winters* *Longer warmer summers*	*Lower winter pest mortality* *Increased pest productivity*	*Increased pest populations likely to harm oak trees* *As above*	*Med* *Med* *High*	*Now* *5-10 years* *15-25 years*

Column 1 is populated by Step 1 of the assessment and column 2 from Stage 2 and Table 1.

Columns 3 and 4 are from this section of the assessment, Step 3.

Columns 5 and 6 are populated in Step 4 of the assessment. Column 6 estimates when the climate change impact is likely to have the level of impact level described in column 5, which can record increasing impact with increasing timescale

Table 3: Indirect impacts to <*name work area*> from external factors eg likely sectoral adaptation responses:

Climate change issue	Objective of external adaptation responses	Likely activities to achieve objective	Threats / opportunity to conservation objective / interest	Level of impact	Time of impact
Rising atmospheric CO2 concentration	*Increase yield*	*Crop breeding including GM*	*Increased GM crop issues*	*Low*	*5-15 years*
		Field management changes	*Changing management may change conditions for farmland birds e.g. earlier, denser sward, changes in inputs etc;*	*Medium*	*10-20 years*
		New crops	*Depends on crops: threats and opportunities*	*Medium*	*Current / ongoing*
Reduced summer water availability in East Anglia	*Agricultural interests seek to secure water for farming*	*Research; political / public lobbying*	*Farm water demand displaces water used for conservation*	*High*	*10-20 years*

Step 4 Identify key threats and opportunities from climate change

What is the aim of this?

- To prioritise the impacts of climate change for action. This should take into account both scale of change and timing likely to be required.

From Step 3, prioritise what the key implications of climate change are likely to be for your objectives / activities / operations. Prioritisation is based on the combination of degree of impact and timescale of impact. Assign three levels of priority for each assessment. Use high, medium and low levels for both likely threats and likely benefits. To assess the time frame for action, use Short, Medium and Longer Term (within the next five years, five to 15 years, 15 to 30 years). Remember also that there are likely to be opportunities as well as problems and threats from new climatic conditions.

You should also consider the urgency of taking adaptive action, and plan for the longer term action that may be required.

Consider also the influence of your locally changed situation upon the national, UK or international perspective (e.g. summer water stress contributing to regional wader population declines). Central co-ordination of this information will be needed to assess future achievement of national conservation targets.

How should I organise the information?

The outline assessment of impact and timescale is recorded in Columns 5 and 6 of Tables 2 and 3.

You are then likely to need to prioritise the list impacts to take forward to Step 5, considering adaptation.

Step 5 Explore actions to address the impacts of climate change

What is the aim of this?

- To explore options for effective adaptation.

Adaptation is all about taking practical action to achieve the best outcomes in a world of changing climatic conditions. This may be simple and straightforward in some cases, but in others it will require imaginative and flexible action. As well as considering actions required now, we all need to plan ahead for actions that may be required under particular future conditions.

This step therefore requires some consideration of whether your conservation objectives, and your strategic approaches to meeting those objectives, need revising. Timescales are also important to consider, both to allow time for the effective implementation of responses, and because climate conditions will continue to change: adaptation is a process of 'change management'. The columns in Table 4 take you through these considerations.

Two strategic directions. Adaptation actions fall within two broad categories: those designed to build resilience against climate change; and those to accommodate change. These are not mutually exclusive and actions for both can, and often will, be taken concurrently. In some cases they may even be the same thing: for example building stronger populations today, increases opportunities for dispersal to new locations with suitable climate conditions.

The early emphasis of adaptation is more likely to be focused on building resilience. This should not foreclose thinking about actions need to accommodate inevitable changes in biodiversity that climate change will bring, and how national objectives will need to be met through changes in local delivery. The balance of effort across these two types of action will be a key consideration for the success of many adaptation strategies over time, as climate change increasingly exerts its influence.

Exploring potential adaptation responses may address a range of different issues. Examples include:

- direct climatic change: e.g. micro-habitat, hydrological provisioning, windbreaks, shade planting etc.
- ecological issues: e.g. food sources, species associations, habitat change
- reducing non-climate stresses: e.g. over-grazing, disturbance, pollution
- encouraging distribution shifts e.g. increasing population strength to encourage dispersal, creating new habitat, providing ecological connectivity, etc.
- building adaptive capacity into existing systems: e.g. making provisions for future species distributions through spatial planning, considering potential future value of land proposed for a development for biodiversity and / or human adaptation (e.g. flood control).
- sustainability: both in terms of undertaking the initial response, and its contribution to social, economic and environmental sustainability

The impacts of climate change may change your objectives, particularly over a period of time. This is likely to reflect a shift in emphasis from increasing resilience of your conservation interests to climate change, to accommodating objectives to future climate conditions. Some actions to accommodate to future conditions may have long lead-in times, such as the creation or development of habitat to help shifts in species' distributions.

At the present time, the focus of climate change adaptation is expected to be given mainly to revising actions and strategies to meet existing objectives. Nonetheless thought should also be given to modifying objectives, as species distributions shift and local conditions change, influencing the type of habitat management, for example, that is both desirable and possible.

For example, building breeding wader populations at some south-east England sites may be achievable for the next 10 to 25 years, and be important to build strong, dispersing populations able to colonise newly suitable areas in the future. Longer term, this may be untenable at current locations, whose role in developing adaptation will subsequently change. Clear recognition of this development of objectives will help to guide both local and national adaptation planning.

Further information to guide adaptation actions and planning is given in the Annex.

How should I take this forward?

Developing adaptation actions is likely to be best considered by a group with a mix of expertise. It may also require and identify further research and so may be an ongoing process. Estimates should also be made for cost and time required to undertake actions.

Actions may be either generic or specific, for either a particular aspect of climate change, or for a particular impacted interest. Creating a central resource of ideas, knowledge and experience will be help build efficiency across the RSPB's adaptation planning – see Steps 7 and 8.

How should I organise the information?

Table 4 brings together the key impacts of climate change on your objectives and summarises what should be done as consequence.

Table 4: Adaptation responses for <*name work area*>:

Impact, threat or opportunity	Objective of adaptation	Strategy to achieve objective	Key actions	Priority	Timescale to achieve adaptation
Drier summers causing issues for summer breeding waders	*Maintain strong breeding populations in current areas*	*Reduce abstraction pressure in catchment*	*Target farm irrigation demand / more suitable crops*	*Med*	*Changes needed by 2020*
		Store more winter water on RSPB reserves	*ID reserves, research potential landholdings, volumes, costs*		*Include in reserves management plan reviews-ongoing*
		Increase wetland areas in floodplains	*Work with water management bodies to increase natural flood control*		*2020*
Pest and diseases	Reduce pest damage	Reduce suitability for pest invasion	*Research ecological resistance to pest invasion for xxx and yyy*	*Med*	*Results 3-5 years*
	Reduce pest numbers	Pest eradication	*Secure Defra policy / guidelines and action*	*High*	*Revised guidelines 2015*

Column 1 is populated from the fourth column of Tables 2 and 3, (direct and indirect impacts). You may want to summarise and/or amalgamate the information in those columns to produce a workable list of impacts that you can address.

Developing the strategic approach (column 3) may involve a wide range of approaches, policy, public relations, marketing, community and other responses, as well as direct conservation management responses.

Step 6 Decide what actions should be taken and revise operational activities accordingly

What is the aim of this?

- To agree and action the practical adaptation best able to meet objectives.

Prioritise adaptation actions and select those to be taken forward. This should include recognition of actions likely to be needed in the future, as well as those for early implementation.

Give particular focus to:

- No regrets actions that are robust across the range of expected future climate conditions
- Win-win actions that have additional benefits to core objectives, providing ecosystem based adaptation and/or services to other sectors e.g. flood control or carbon storage
- Involvement of partnerships for co-delivery
- Costs and opportunities for co-funding
- The sustainability of different options, aiming to choose, where possible, the most sustainable option.

Actions at this stage are likely to contribute to existing strategies, and be an embedding of adaptation and climate change into our current objectives. They will also help to develop our current strategies, for example, understanding species vulnerability to climate change will contribute to prioritisation of species in the species recovery strategy.

How should I organise the information?

Table 4 outlines your adaptation options. You should prioritise these options, and integrate appropriate responses in your strategies, actions and work programmes. This will probably include both the detail required for action that may be required over the next five years (or to 2020) as well as likely actions required thereafter (Medium and Longer Term as per Step 4), as climate change progresses towards a 2°C world around 2040. Any estimate costs may need to be assessed more thoroughly, and consideration given to budget requirements.

influencing the type of habitat management, for example, that is both desirable and possible.

Step 7 Monitor and review

What is the aim of this?

- To assess the effectiveness of the implementation and ongoing performance of adaptation actions as climatic conditions change and to modify adaptation actions as required.

Adaptation action should include devising monitoring requirements to test the effectiveness of the adaptation actions undertaken. This should assess the deployment of the actions themselves and their role as integral components of the wider workplan activities and objectives. A key objective of this monitoring will be to find out what adaptation actions work well, and so to be able share learning and expertise. Monitoring requirements should be integrated with the implementation of adaptation actions.

Biological monitoring of the results of adaptation actions will usually be picked up by, and integrated into, current national monitoring programmes. These may require some modification as climate change introduces new concerns and priorities, and potentially new time scales, into our work. The national monitoring schemes should thus also provide information to guide adaptation, providing information on habitat, population and distribution changes, as the influence of climate change increases.

How should I organise the information?

Set up regular review of monitoring results appropriate to methods and speed of change:

- develop adaptation actions as appropriate
- develop activities and objectives of the wider programme / interest as appropriate

Step 8 Communication – internal and external, spread best practice

What is the aim of this?

- To share experience and expertise on climate change adaptation and build capacity
- To build support and advocate for appropriate adaptation action.

Time constraints in the workshop programme allow only a short discussion on communications. Adaption brings new problems to solve, and new expertise and experience gained. Discussing approaches and sharing experience helps to build more concerted and effective adaptation for nature.

Adaptation also provides some 'good news' stories for supporters and the wider public. Using ecosystem approaches for adaptation can help build awareness of the value of the natural environment. Adaptation also helps to make climate change become more real for more people, making responses to climate change more commonplace in society and helping to address feelings that climate change is too big and too distant to be able to do much about.

Summary statement

The tables record the discussion and thought processes of the workshop, yet its also useful to have a succinct report summarising climate adaptation. The following headings provide the essential structure for such a report, which ideally should be non-technical, and brief – two to four pages of A4:

- Two sentence overarching summary
- What are the key climate changes expected for a 2°C world? How different would a 4°C world be likely to be from this?
- What are the main changes that climate change is likely to bring?
- What current activities are helping to meet the challenges of climate change?
- What will we need to do differently because of climate change? Are there new things that we'll have to do to adapt successfully? What are the time frames for action, and who needs to be involved?

Butterfly bank under construction, RSPB Winterbourne Downs Nature Reserve, Wiltshire © Patrick Cashman/RSPB

Annex – some useful pointers towards successful adaptation

Five principles for adaptation to climate change are identified by the England Biodiversity Strategy[1] :

- Maintain and increase ecological resilience
- Accommodate change
- Develop knowledge and plan strategically
- Integrate action across all sectors
- Take practical action now

Four things useful to consider, when starting to think about embedding climate change into work programmes:

- **Ongoing**. Adaptation is a continuing journey of progressive change over a period of years and decades. For example, nature conservation cannot just adapt to meet future, worst-case climate conditions – it has to provide suitable conditions for wildlife in the intervening years, too. While there may well be urgent, short term actions, adaptation also needs forward planning and investment of time.
- **Action now**. Anticipatory action is likely to be cheaper and more efficient and we should seek to avoid future emergency remedial action. While timescales for habitat creation are perhaps obvious, thinking ahead is important for less extreme adaptation actions too: for example having a sense of future direction helps steer partnerships, and allows time for developing appropriate adaptation.
- **Planning ahead**. There is considerable uncertainty in the detail of climate change projections, and of how biodiversity may respond. Yet the overall direction of change is clear, and we need to learn to make decisions in this context. Adaptation will need to address a wide range of conditions and so will require flexibility in our approach and in our decision-making, with recognition that we need room for error. We should expect to have less uncertainty for the near-future, than for further ahead.
- **Flexibility**. Biodiversity and ecosystems are naturally dynamic, which adaptation should recognise. Climate change will bring further change and dynamism to ecosystems, and this needs to be recognised, separately from natural background change. The chaotic nature of the weather may also cloud recognition of changing climatic trends, yet also emphasises that adaptation is likely to have to address a wide range of conditions
- **How will people adapt?** Considerations of societal and sectoral adaptation may help integrate environmental adaptation, through ecosystem-based approaches for adaptation and ongoing provision of ecosystem services.

1 Climate Change Adaptation Principles: conserving biodiversity in a changing climate. Smithers *et al* Defra 2008

Some further points that may be useful in considering climate change adaptation:

- Climate change impact results from the combination of the amount of exposure, and degree of sensitivity, to different climatic conditions. Adaptation action may address these independently, or simultaneously.
- Vulnerability is a combination of the degree of impact, as above, and the potential for successful adaptation: effective adaptation will reduce vulnerability. Overall risk from climate change would include measures both of the degree of impact, and of vulnerability.
- Adaptation may either be autonomous (e.g. species moves location, or switches to a different food source) or externally delivered (e.g. conservation action, or societal response) or a combination of both (e.g. habitat enhancement to improve conditions for natural dispersal). Understanding what autonomous adaptation is likely will help guide our actions.
- Adaptation is likely to be ongoing - there is no known end-point for climate change – so early actions may eventually shift to different actions over time
- Uncertainty in knowledge about future climatic conditions, and about the response of both natural and human systems to climate change, means that actions must be appropriate to cover a range of future scenarios – 'no regrets' actions.
- Adaptation for biodiversity conservation will often be undertaken with other interests, which are also developing adaptation responses. Devising adaptation strategies and actions for biodiversity that contribute ecosystem based adaptation or benefits to other sectors, and are sustainable in a wide context, are more likely to be successfully adopted - 'win-win' actions.

Contact

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Part 2
Habitats

Introduction

This section of the manual considers the potential impacts of climate change on individual priority habitats and outlines possible adaptation responses. It is intended to help those responsible for managing such habitats to think about the likely impacts in their area and to identify appropriate management responses. It is not intended to be prescriptive – it provides evidence, information and resources so site managers can make their own decisions. The section takes the form of a series of stand-alone habitat 'sheets' that can be printed individually as needed. The information contained in the habitat sheets is based on documented evidence interpreted with the expertise and experience of staff in Natural England, the RSPB, the Environment Agency, and the Forestry Commission. References to underpinning source documents are provided.

Each habitat sheet is structured as follows:

- **Overall habitat sensitivity**. This provides an assessment of the relative sensitivity of the habitat to climate change and is derived from a basic classification of UK habitats (see table 1) originally published in the England Biodiversity Strategy, and revised in the development of Natural England's **National Biodiversity Climate Change Vulnerability Model** (described in part 1) and in the development of this manual. The most sensitive habitats are those whose existence is dependent on specific climatic, hydrological or coastal conditions, which projections indicate are likely to change. The least sensitive habitats are those that are determined by factors such as grazing or geology, and where climate plays a minor role. It should be noted that these classifications are generalisations based on an assessment of the habitat itself, and that species within the habitat may show a variety of sensitivities to climate.
- **Introduction**. This highlights the main sensitivities and key issues for the habitat.
- **Potential climate change impacts**. This sets out in table form the most likely potential climate change impacts on the habitat, in relation to specific climatic variables (causes) and their consequences. The tables focus mainly on the direct impacts of climate change, but where there is a strong likelihood that a changing climate could lead to significant indirect impacts, these have also been included.
- **Adaptation responses**. This section describes possible approaches to adaptation for the habitat in question, and suggests a range of potential adaptation actions. These will not all be appropriate to individual sites, but are intended to portray a range of possible management responses that might be considered. The adaptation actions listed are intended to be a guide only and will need to be adapted to reflect local circumstances.
- **Relevant Countryside Stewardship options**. This highlights the most appropriate options that are available under the Countryside Stewardship Scheme. Information about this scheme and the land management options and payment rates can be found on the **Government's Countryside Stewardship web pages**.
- **Further information and advice**.
- **Relevant case study examples (where available)**.
- **Key evidence documents**. This lists the main reports, journal papers, and other publications that have helped to inform the habitat sheet.

Table 1: Relative sensitivity of habitats to climate change

Habitat	National sensitivity classification
Coastal Saltmarsh	H
Montane	H
Saline Lagoons	H
Standing Water	H
Lowland Fen	H
Rivers and streams	H
Upland Hay Meadows	M
Coastal Grazing Marsh	M
Lowland Raised Bog	M
Floodplain Grazing Marsh	M
Purple Moor Grass and Rush Pasture	M
Coastal Vegetated Shingle	M
Lowland Meadows (wet)	M
Reedbeds	M
Blanket Bog	M
Coastal Sand Dunes	M
Upland fens and flushes	M
Lowland Heathland	M
Upland Heathland	M
Intertidal Mudflats	M
Lowland beech and yew woodlands	M
Wet woodland	M
Upland mixed ashwoods	M
Upland oak wood	M
Maritime Cliff and Slope	M
Limestone Pavements	L
Lowland Meadows (Dry)	L
Deciduous Woodland	L
Lowland Calcareous Grassland	L
Lowland Dry Acid Grassland	L
Upland Calcareous Grassland	L
Arable field margins	L
Ancient/species rich hedgerows	L
Lowland wood pasture and parkland	L

Classification adapted from Mitchell *et al* **(2007) England Biodiversity Strategy – Towards adaptation to climate change.**

List of habitat sheets

Thorpe Wood, Peterborough, Cambridgeshire
© Natural England/Peter Wakely

1. Lowland mixed deciduous woodland

Climate change sensitivity: **Low**

Introduction

The greatest threat to woodlands from climate change is likely to be an increase in the frequency and severity of summer drought. There is a high likelihood that there will be impacts on drought-sensitive tree species, particularly on some soil types (e.g. shallow, freely-draining soils and clay soils), particularly in predominantly in southern and eastern England.

Stressed trees are more susceptible to insect pests and diseases, and the majority of insect pests that currently affect UK woodlands are likely to benefit from climate change as a result of increased activity and reduced winter mortality (Broadmeadow 2005). The impacts of both insect pests and diseases are therefore likely to increase with climate change. Deer and grey squirrel *Sciurus carolinensis* populations are also likely to benefit from climate change, representing a greater threat to woodlands and limiting the capacity for evolutionary adaptation through natural regeneration.

There are likely to be shifts in the distribution of the main tree species across much of the UK and, due to the low species diversity of high forest trees in England's woods; over a long time-frame this may result in widespread change to the composition and structure of woodland.

The risk of wind-throw may increase if the UK experiences more storms or if tree-root depth becomes restricted by increased rainfall and water-logging.

The likely responses of the forestry sector to climate change may change the character of broadleaved woodlands as new management approaches, including the planting of native and non-native species in locations outside their natural range, are adopted. However, the more widespread adoption of continuous cover systems of management could benefit some woodland biodiversity through improvements in stand structure.

Habitat Description

Mixed deciduous woodland is characterised by trees that are more than 5 m high when mature, and which form a distinct, although sometimes open, canopy with a canopy cover of greater than 20%. It includes stands of both native and non-native broadleaved tree species, as well as yew *Taxus baccata*, where the percentage cover of these trees in the stand exceeds 80% of the total tree cover. Deciduous woodland may be of ancient or recent origin, and can be either semi-natural arising from natural regeneration or planted.

Deciduous woodlands are widespread across England. Distinct patterns of woodland are often related to landscape history. Large gaps in the distribution of broadleaved woodland often correspond to former lowland wetlands, such as the Fens or Somerset Levels; linear woods along valley sides or rivers are typical of the uplands of Cumbria or Northumberland; clusters of large woods are often associated with former Royal Forests, such as Rockingham (Northamptonshire), or where there were extensive wood-using industries (such as The Weald and the Chilterns); while in prime farming counties such as Suffolk and Leicestershire woods are often small and scattered (Natural England 2008).

There are an estimated 961,000 ha of broadleaved woodland in England (Forestry Commission 2012).

Potential climate change impacts

Cause	Consequence	Potential impacts
Warmer winters		■ Earlier bud burst, with potential for increased risk of frost damage. ■ Incomplete winter hardening, potentially resulting in more serious winter cold damage. ■ Reduced winter chilling, leading to reduced seed germination and natural regeneration of some species. ■ Greater survival of mammal pests (e.g. deer and grey squirrel), resulting in increased grazing pressure and decreased regeneration. ■ Greater overwintering survival of insect pests, leading to increased abundance and pressure.
Altered seasonal rainfall patterns	Increased fluctuation in water tables and winter flooding	■ Increased infection by various soil and water-borne pathogens such as Phytophthora. ■ Reduced rooting depth for species intolerant of winter water-logging, exacerbating the effects of summer drought. ■ Increased likelihood of wind-throw if tree root depth becomes restricted by increased rainfall and water-logging.
Drier summers	Drought Fire	■ Shifts in the composition of native woodland communities/types (Broadmeadow *et al* 2009a, 2009b). ■ Increased competition from invasive species and the potential establishment of species from further south in Europe e.g. holm oak. ■ Shifts in the regeneration patterns of trees. ■ A potential decline in canopy cover. ■ Changes in ground flora composition. ■ Rapid changes in canopy characteristics and composition on very dry sites.
Increased frequency of extreme events	High winds Extremes of soil temperature and moisture	■ Increased frequency of wind-throw, leading to losses of mature and veteran trees. ■ The loss of specialist species associated with veteran tree habitat (primarily fungi, invertebrates and lichens). ■ Increased frequency of environmental stress. ■ Potential for widespread tree mortality in years of extreme drought.
In combination	Increased prevalence of pathogens Increased survival of disease vectors Increased survival of mammal pests such as deer and grey squirrel Changed patterns of woodland productivity	■ Potential loss or significant reduction in the abundance of key canopy species. ■ Limited natural regeneration. ■ Introduction or increased levels of planting of non-native species.

Adaptation responses

Appropriate adaptation responses will differ across the country because the landscapes, woodland, what is expected of them, and the climatic pressures, differ. However, even within a single landscape, the critical factors may vary: changes in winter rainfall might be important for valley bottoms, whereas summer drought could be critical on adjacent south-facing slopes (Kirby *et al* 2009).

Management of existing woodland is likely to focus on the reduction of non-climatic pressures such as pests and diseases, increasing the species and genetic diversity of new and existing woodland to reduce the impact of changes in the abundance of single species, and encouraging natural regeneration (i.e. evolutionary adaptation) by reducing grazing pressures from deer and thinning to create canopy gaps. However, in many cases acceptance and management of change will also be a key adaptive response to climate change.

Measures that aim to reduce the impact of drought and ensure the availability of water are likely to be increasingly important in different woodland types across the country.

For new woodland planting and, in some cases restocking, species and provenance selection will increasingly need to reflect projected future climatic conditions.

Some of the potential adaptation options for this habitat are outlined below:

Existing woodland

- Reduce the impacts of other pressures, such as pests and diseases, pollutants, over-grazing and development. Reducing deer pressure, for example, allows more flowering and seed setting of ground flora such as primroses, so increasing the potential for populations to survive drought years.
- Undertake management interventions to encourage and protect regeneration.
- Assess future suitability of species present on the site using Ecological Site Classification; assess options for species diversification.
- Accept and encourage a greater mix of native trees and shrubs through active management, for example by accepting a greater component of oak in the canopy of 'beech woods'.
- Increase the age structure and structural heterogeneity of woodland, for example by reducing coupe size and encouraging continuous cover forestry rather than large-scale clear felling.
- In woodland managed for timber, continuous cover forestry approaches may become more advantageous because they are thought to be more wind-firm, maintain a more even carbon storage, show lower soil carbon losses during harvesting, and promote recruitment by maintaining higher humidity levels (Kirby *et al* 2009).
- Consider blocking artificial drainage channels within woodland in areas predicted to experience increased drying out.
- Manage veteran trees to reduce the crown-to-root ratio, and improve protection for individual veteran trees.
- Undertake contingency planning for outbreaks of new pests or major new disturbance events such as wildfire.

- Critically assess the ecological role of near native species and consider accepting as a component of semi-natural woodland beyond their current native range, e.g. sycamore.
- Reflect management changes and potential changes in native tree composition in conservation objectives and guidance.
- Review objectives for woodland in relation to the wider suite of ecosystem services that woodlands provide. For example, outside designated sites and ancient woodland, changes in species composition, including the retention of non-native/exotic species, may be acceptable if the services that the woodland provides, such as urban cooling, visual amenity or recreational opportunities, remain intact.
- When determining the optimal management of sites, consider the requirements of key species such as woodland birds to ensure minimum patch size is retained.
- Take positive steps in all woodland situations to increase the proportion and diversity of decaying wood throughout sites. This will ensure both resilience of dependent species and the replenishment of woodland soils' organic content and hence the capacity for moisture retention and provision of other essential ecological functions needed by trees and other species.

New planting

- Assess options for species choice on the site using Ecological Site Classification (ESC) and an understanding of soil types present.
- On more free-draining soils in southern and eastern England, select more drought-tolerant species.
- In the southern and eastern parts of the country, and in locations prone to drought, use new planting to increase the patch size of small woods and reduce edge effects. This will help reduce water loss and also the effects of spray drift from adjacent farmland.
- Develop woodland and semi-natural habitat networks through planting new woodlands in targeted locations.
- Include a greater mix of species within new native woodland planting, including less commonly planted native species and, where ecologically appropriate and likely to benefit from projected climate change, near-native species from outside their current natural range should also be considered.
- Encourage a variety of species that can occupy the same functional space within the woodland ecosystem.
- Identify locations for planting where the direct impacts of climate change on the suitability of individual species may be less than in the surrounding region. These could include north-facing or more sheltered slopes and areas with more secure water supply such as spring lines or low lying areas closer to the water table (though these may be valuable open features themselves).
- Consider the potential for tree planting to assist adaptation in other sectors, for example as shading for livestock, windbreaks, and flood alleviation.
- Consider higher density planting so that woodland can be economically managed in the future to maintain habitat condition and continue to adapt to progressive climate change.

- When establishing new woodland or restocking, consider the planting of more southerly provenances of native species where this is consistent with site objectives.
- Improve understanding of soil properties and heterogeneity across the site, including the requirements of individual species and how these may change as climate change progresses.
- Retain/encourage field layer (minimal use of herbicides and mowing regimes) in combination with the use of biodegradable mulch mats during establishment phase to minimise soil water loss and buffer soil temperature variation which make a significant contribution to losses.
- Consider promoting natural colonisation to generate new semi-natural woodland adjacent to existing woodland, allowing locally native species to develop resilience through natural processes.

Relevant Countryside Stewardship options

WD1 Woodland Creation - maintenance payments

This option aims to support the successful establishment of newly created woodland that provides environmental and/or social benefits including:

- Supporting wildlife, particularly where new woodland links habitats or provides a protective buffer.
- Help reduce flood risk, improve water quality and prevent soil erosion.
- To create woodland that is resilient and can adapt to climate change.
- Landscape enhancement.

WD2 Woodland improvement

This option aims to change the woodland structure or management regime to improve biodiversity or enhance resilience to climate change. Dependent on the operation, multi-annual agreements will show a gradual restructuring or improvement in the condition of the woodland.

Further information and advice

Forestry Commission, **Climate change impacts and adaptation in England's woodlands**.

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Beech and Yew – Wealden Edge Hangers SSSI, Hampshire
© Natural England/Peter Wakely

2. Beech and yew woodland

Climate change sensitivity: **Medium**

Introduction

Beech is sensitive to drought and is likely to be particularly vulnerable to the projected changes in rainfall and temperature in the south-east of England due to the large area planted on thin, freely-draining soils. However, widespread losses are unlikely, although on less suitable soils with a southern aspect the species is likely to decline. The climate is projected to become more suitable for beech in the north and west.

Being thin barked, beech is particularly vulnerable to climate change driven increases in mammal pest species such as grey squirrels. More generally, stressed trees are more susceptible to insect pests and diseases. The majority of insect pests that currently affect UK forestry are likely to benefit from climate change as a result of increased activity and reduced winter mortality. These impacts are likely to affect the commercial value of beech and lead to changes in the composition of both the canopy and ground flora of beech and yew woodland.

Habitat Description

The composition of lowland beech and yew woodland varies according to soil and topographical conditions. Beech *Fagus sylvatica* can grow on both acidic and calcareous soils, although its association with yew *Taxus baccata* is most common on calcareous sites. They are often found as part of a mosaic with other mixed deciduous woodland communities.

Calcareous beech and yew woodland commonly occurs on the limestone and chalk outcrops of southern Britain and forms perhaps 40% of the total lowland beech and yew habitat. The majority of stands have a high forest structure. The canopy can include a mix of beech, ash, sycamore, yew and whitebeam. Oak is less common than in the other beech woods, and pure stands of yew occur in places. Promotion of high quality beech for silviculture has often led to an artificial dominance of beech. Characteristic uncommon or rare plants associated with beech and yew woodland include box *Buxus sempervirens*, red helleborine *Cephalanthera rubra*, coralroot bitter-cress *Cardamine bulbifera*, and bird's nest orchid *Neottia nidus-avis*.

Beech woodland on neutral to slightly acidic soils comprises about 45% of the total habitat. It is usually found on heavier soils and often where the drainage is poor or impeded. The boundary with the other beech types is often defined by pH (in the range 7 to 4), drainage and soil texture; thus it is common to find this type grading into one of the others. Again, stands tend to be dominated by beech, but commonly contain English Oak *Quercus robur* and sometimes Sessile Oak *Q. petrea*. Bramble *Rubus fruticosus* forms a characteristic ground layer. Often there is no shrub layer, although holly *Ilex aquifolium* can form a second tier of trees, occasionally with yew. Violet helleborine *Epipactis purpurata* is a rare plant found in these communities. Mosaics with oak/bracken/bramble woodland are common, and in some areas beech can be found colonising western oak woods. This woodland type tends to occur as high forest or relict wood-pasture (with pollards), and less often as abandoned coppice.

Acidic beech woodland forms the remaining 15% of the habitat type. This usually occurs as high forest, but also makes up a large percentage of lowland wood pasture sites. Acidic beech stands are usually found on light, sandy or sometimes gravelly soils that are well-drained (pH 3.5 to 4.5). Holly, and sometimes yew, is the main understorey species, with oak being the most commonly associated canopy species. Mosaics with oak/birch/wavy-hair grass communities are common. The western edge of its range is ill-defined, and beech clearance from, and spread into, western oak woods occur in almost equal measure.

There are no precise data on the total extent of native lowland beech and yew woodland in the UK. In the late 1980s the Nature Conservancy Council estimated the total extent of ancient semi-natural woodland of this type at between 15,000 and 25,000 ha, which, with recent beech woodland planting, brings the total area to about 30,000 ha.

Potential climate change impacts

Cause	Consequence	Potential impacts
Drier summers	Drought	■ Mature beech trees are sensitive to drought and seasonally fluctuating water tables on less suitable soil types. This can lead to reduced growth, die-back and death (Hearn & Gilbert 1977; Geßler *et al* 2007). ■ Reduced abundance of beech specialists (e.g. epiphytes, fungi, invertebrates). ■ Changed ground flora composition.
Wetter winters	Spring water-logging	■ Reduced nutrient uptake and reduced vigour of beech (Carey 2013; Geßler *et al* 2007). ■ Increased susceptibility to summer drought.
Warmer summers	Prolonged periods of heat	■ Increased sun-scorch, leading to bark-death in beech.
Warmer winters	Fewer frost events	■ Reduced winter cold periods leading to reduced bud initiation and a possible reduction of beech in parts of Britain. ■ Increased fecundity and survival of mammal pests, resulting in more damage to thin barked trees and reduced regeneration. ■ More generations of insect 'pests' per year (Read *et al* 2009).
Increased frequency of extreme events	High winds	■ Increased loss of trees to wind blow. Most damage to woodlands is caused by extreme events and the frequency of these is very difficult to predict.
In combination		■ Increased prevalence of fungal pathogens, including *Biscogniauxia* species, which cause damaging strip cankers on beech (Hendry *et al* 1998).

Adaptation responses

As with other woodland habitats, there are likely to be changes in both the abundance of the habitat and the composition of species within it. In the south and east, reduced water availability will drive succession to other woodland types such as oak (especially English oak on heavier soils) or to scrub habitat, depending on soil depth, soil water holding capacity and the change in rainfall seasonality. Conversely, the vigour of beech in the north of its existing range will increase and it will become increasingly viable outside its current range.

The acceptance of change will therefore be a key response, with management to increase the resilience of beech woodland focusing on the reduction of non-climatic pressures and reducing the impact of drought.

Some of the potential adaptation options for this habitat are outlined below:

- Reduce the impacts of other pressures, such as pests and diseases, pollutants, over-grazing and development pressures. Reducing deer grazing pressure, for example, allows more flowering and seed setting of ground flora, such as primroses, therefore increasing the potential for populations to survive drought years.

- In the southern and eastern parts of its range, and in locations prone to drought, increase the patch size of very small sites and ensure new planting is designed to reduce edge effects by avoiding linear planting. This would help reduce water loss and spray drift from adjacent farmland.
- Consider soil type, aspect and topography carefully when evaluating woodland expansion options, including assessment using Ecological Site Classification, and use these features to maintain/enhance future suitability of the species.
- Where new planting is being considered, potential refugia need to be identified where the direct impacts of climate change may be less than in the surrounding region. These could include north facing or more sheltered slopes and areas with a more secure water supply (e.g. spring lines or low lying areas closer to the water table).
- Increase the age structure of high forest to reduce the susceptibility of beech populations to damage from droughts and storms.
- Accept a greater mix of native trees within the canopy of beech woods, including oak on non-calcareous soils, and smaller trees such as holly, whitebeam and birch.
- Where the climate is projected to become suitable, accept beech as component of semi-natural woodland in areas beyond its current native range.
- Take positive steps in all woodland situations to increase the proportion of decaying wood to ensure resilience of dependent species, the replenishment of soil organic content and the capacity for moisture retention.

Mature beech in Buckholt Wood, Gloucestershire © Natural England/Peter Wakely

Relevant Countryside Stewardship options

WD1 Woodland Creation - maintenance payments

This option aims to support the successful establishment of newly created woodland that provides environmental and/or social benefits including:

- Supporting wildlife, particularly where new woodland links habitats or provides a protective buffer.
- Helping to reduce flood risk, improve water quality and prevent soil erosion.
- Creating woodland that is resilient and can adapt to climate change.
- Landscape enhancement.

WD2 Woodland improvement

This option aims to change the woodland structure or management regime to improve biodiversity or enhance resilience to climate change. Dependent on the operation, multi-annual agreements will show a gradual restructuring or improvement in the condition of the woodland.

Further information and advice

Buglife. Advice on managing BAP habitats **Lowland Beech and Yew Woodland**.

Forestry Commission **The management of semi-natural woodlands: Lowland beech-ash**.

Forestry Commission England 2010, Practice Guide **Managing ancient and native woodland in England**.

JNCC (2008) UK BAP habitat description **Lowland Beech and Yew Woodland**.

Forestry Commission (2003) **Restoration of Native Woodlands on Ancient Woodland Sites**.

Relevant case study examples

Chiltern Woodlands Project

The aim of the Chiltern Woodlands Project is to promote and encourage the sensitive and sustainable management of Chiltern woods in order to protect the landscape of the Chilterns and maintain and enhance its biodiversity.

Key evidence documents

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Upland Oak. Johnny Wood SSSI, Borrowdale
© Natural England/Peter Wakely

3. Upland oak woodland

Climate change sensitivity: **Medium**

Introduction

The trees in upland oak woods are likely to be relatively resilient to the projected changes in climate over the short to medium term, with little change in the distribution of the main species (Berry *et al* 2001, 2003). However, the high abundance and diversity of ferns, bryophytes and lichens in upland oak woods is associated with a cool, wet climate, and a transition to warmer, drier summer conditions could result in a significant change in their character. Changes to the phenology and vigour of the canopy trees may have impacts on ground flora.

Upland oak woods may come under increasing pressure from both native and non-native invasive species, and from the spread of potentially injurious pathogens.

Habitat Description

Upland oak woods are characterised by a predominance of oak (mostly sessile *Quercus petraea*, but locally pedunculate *Quercus robur*) and birch *Betula spp* in the canopy, with varying amounts of holly *Ilex aquifolium*, rowan *Sorbus aucuparia* and hazel *Corylus avellana* as the main understorey species.

The range of plants found in the ground layer varies according to the underlying soil type and degree of grazing, and ranges from bluebell-bramble-fern communities through grass and bracken dominated ones to moss-dominated areas. Most oak woods contain areas of more alkaline soils, often along streams or towards the base of slopes, where much richer communities occur, with ash and elm in the canopy, more hazel in the understorey and ground flora such as dog's mercury *Mercurialis perennis*, false brome *Brachypodium sylvaticum*, Ramsons *Allium ursinum*, enchanter`s nightshade *Circaea lutetiana*, and tufted hair grass *Deschampsia cespitosa*.

Elsewhere, small alder stands may occur, or peaty hollows covered by bog mosses *Sphagnum spp*. These elements are an important part of the upland oak wood system. The ferns, mosses and liverworts found in the most oceanic of these woods are particularly rich. Many also hold very diverse lichen communities and the woods have a distinctive breeding bird assemblage, with redstarts *Phoenicurus phoenicurus*, wood warblers *Phylloscopus sibilatrix*, and pied flycatchers *Ficedula hypoleuca* being associated with them throughout much of their range. In the south west of England, the rare blue ground-beetle *Carabus intricatus* is associated with this habitat.

Upland oak woods are found throughout the north and west of England, with major concentrations in Cumbria, Devon and Cornwall. Related woodland does occur on the continent, particularly in the more oceanic areas, but the British and Irish examples are recognised internationally as important because of their extent and their distinctive plant and animal communities. For some of these species, Britain and Ireland hold a substantial part of the world/European population.

Many upland oak woods were intensively managed for charcoal until the late 1800s and many were felled in the two World Wars. Between 1930 and 1985 about 30% of the area was replanted with conifers, but many of these areas are now being restored. Some areas were cleared to create pasture, but elsewhere there has been some natural expansion. There is an estimated 30-40,000 ha of upland oak woodland across England.

Potential climate change impacts

Cause	Consequence	Potential impacts
Increased mean temperature	Longer growing season and altered phenology	■ Decline of boreal and sub-boreal bryophyte and moss species at their range margins in the UK, especially in southern-most sites (Ellis 2012). ■ Potential breakdown in synchrony between species due to changes in the time of flushing, for example within food webs (Broadmeadow & Ray 2005, Ray, Morison & Broadmeadow 2010) and food availability (Masters *et al* 2005, Read *et al* 2009). ■ Increased shading due to increased and earlier canopy cover leading to changes in ground flora composition and regeneration (Masters *et al* 2005). ■ Increased threat from of the two spotted oak buprestid *Agrilus pannonicus* (Broadmeadow & Ray 2005), a wood-boring beetle associated with acute/sudden oak decline (Denman & Brown 2011).
Warmer winters		■ Potential expansion of *Phytophthora cinnamomi* (Forestry Commission 1999, Bergot *et al* 2004) and potentially P. ramorum (Broadmeadow & Ray 2005), soil borne fungal pathogens responsible for oak dieback. ■ Improved winter survival of mammal pests such as deer species and grey squirrel *Sciurus carolinensis* could lead to reduced regeneration and loss of ground flora.
Drier summers	Reduced soil moisture and drought Increased risk of wildfire	■ Decline and potential loss of sensitive ground flora and epiphytes, particularly ferns, bryophytes and lichens with oceanic distribution patterns (Ray, Morison & Broadmeadow 2010; Ellis 2012). ■ Increased tree stress, leading to greater susceptibility of trees to pests and diseases (Broadmeadow & Ray 2005). ■ Broadleaved trees including oak are relatively resistant to fire, but fires could result in localised changes in ground flora and understorey composition (Ray, Morison & Broadmeadow 2010), and could lead to localised loss of seedling regeneration and established saplings (Ray, Morison & Broadmeadow 2010).
Increased extreme events	Increased frequency of winter gales	■ Rowan and birch could become more dominant in areas affected by wind-blow of oak (Ray, Morison & Broadmeadow 2010).
In combination		■ Increased encroachment from non-native species such as rhododendron, and native species such as beech which are currently more typical of lowland and southern locations (Ray, Morison & Broadmeadow 2010).

Adaptation responses

Actions that reduce the negative impacts of existing pressures such as pollution, over-grazing and neglect are likely to be the main adaptive response for most oak woodlands. The management of invasive species and monitoring and developing suitable management responses to pests and diseases will also be important for certain sites.

In areas likely to suffer from drought, there may be opportunities to identify potential refugia with consistent water supplies, such as at spring lines. Where these are found within existing woodland, they can be protected and managed. There may also be opportunities to plant new woodland in such areas where that is consistent with wider objectives.

Some of the potential adaptation options for this habitat are outlined below:

- Where possible, reduce the impacts of other pressures, such as pests and diseases, pollutants and development pressures.

- Ensure sites are not overgrazed by livestock or deer, with grazing managed to ensure adequate woodland regeneration.
- Implement management such as rotational coppicing, where appropriate, to diversify the age structure and reduce shading. Reducing shading will help encourage natural regeneration. However, in drought-prone sites, maintaining greater canopy cover may be appropriate to reduce water loss and the impacts of drought on ground flora.
- Potential refugia, where the direct impacts of climate change may be less than in the surrounding area, can be identified. These could include north facing or more sheltered slopes and areas with more secure water supply, for example along spring lines or in low lying areas closer to the water table. Patterns of rainfall can also vary significantly in the uplands.
- In the southern and eastern parts of its range, and in locations prone to drought, new planting can be targeted in areas of high landscape heterogeneity, focusing on areas with resilient sources of ground water and on north-facing slopes less prone to drought. A broader mix of native trees within the canopy of 'oak woods', such as beech, rowan and birch, and within the shrub layer, can increase resilience. These potential changes in native tree composition should be reflected in site conservation objectives and guidance.
- Develop contingency plans for outbreaks of pests and diseases, or major new disturbance events such as fires.
- Take positive steps in all woodland situations to increase the proportion and diversity of decaying wood throughout sites so as to ensure both, resilience of dependent species, and the replenishment of woodland soils' organic content and hence capacity for moisture retention and provision of other essential ecological functions needed by trees and other species.

Oak and ferns. Wistman's Wood, Dartmoor. © Natural England/Peter Wakely

Relevant Countryside Stewardship options

WD1 Woodland Creation - maintenance payments

This option aims to support the successful establishment of newly created woodland that provides environmental and/or social benefits including:

- Supporting wildlife, particularly where new woodland links habitats or provides a protective buffer.
- Help reduce flood risk, improve water quality and prevent soil erosion.
- To create woodland that is resilient and can adapt to climate change.
- Landscape enhancement.

WD2 Woodland improvement

This option aims to change the woodland structure or management regime to improve biodiversity or enhance resilience to climate change. Dependent on the operation, multi-annual agreements will show a gradual restructuring or improvement in the condition of the woodland.

Further information and advice

Forestry Commission (2003), **The management of semi-natural woodland 5. Upland Oakwoods**.

Cumbria Wildlife Trust **Atlantic Oak Wood**

JNCC (2008) UK BAP habitat description **Upland Oakwood**.

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Upland mixed ash woodland. Crathes Castle, Aberdeenshire
© Forestry Commission Picture Library

4. Upland mixed ash woodland

Climate change vulnerability: **Low**

Introduction

Ash *Fraxinus excelsior* is a widespread native tree species, and forms the major component of most upland mixed ash woods. The fungal pathogen *Chalara fraxinea* (ash dieback) is likely to become a major cause of ecological change in upland ash woodland and this is likely to significantly exceed the impacts of climate change. However, climate change may well play an important role in determining what species replace ash. Significant changes to the canopy and ground flora species composition of upland mixed ash woodlands are possible and potentially an increase in their susceptibility to other climate-driven impacts, such as wind throw, and colonisation by non-native invasive species and other pests and pathogens.

Habitat Description

Upland mixed ash woodland is generally found on base-rich soils in the north and west of England. Besides ash, other trees including small-leaved lime, aspen, alder, rowan, bird cherry and birch may also be present. At the southern end of their range (to the south west) they may also include whitebeam, yew, holly and field maple. The shrub layer consists of a range of species including hazel, wych elm, spindle, wild rose, hawthorn and elder. The ground flora can be very diverse, particularly under the light shade of the ash canopy. Some woods have been invaded by beech and sycamore.

The most extensive examples of mixed ash woodland occur in well drained limestone areas, but the type is also found where there is flushing of nutrients within more acid, poorly drained sites. Often, these latter stands are just small fragments of woodland with irregular margins or narrow strips along flushes, river banks, rock outcrops and steep banks. Many upland mixed ash woods are probably ancient in origin, but ash is a vigorous coloniser of open ground, and some very biodiverse ash woods, such as in the Derbyshire Dales, are mosaics of ancient and recent ash woodland. Many woods have been managed as coppice in the past and others have been wood-pasture, but most now have a high forest structure.

Upland mixed ash woods are among the richest habitats for wildlife in the uplands, notable for flowers such as bluebell *Hyacinthoides non-scripta*, primrose *Primula vulgaris,* wood cranesbill *Geranium sylvaticum* and wild garlic *Allium ursinum*. They can contain rare woodland flowers, such as dark red helleborine *Epipactis atrorubens*, Jacob's ladder *Polemonium caeruleum*, autumn crocus *Colchicum autumnale*, and whorled Solomon's seal *Polygonatum verticillatum*. Some rare native trees are found in these woods, notably large-leaved lime *Tilia platyphyllos* and various whitebeams (*Sorbus spp.*).

Upland mixed ash woods also have a rich invertebrate fauna, which may include uncommon or declining species. Standing and fallen dead wood provides habitat for rare beetles, flies and other invertebrates. The dense and varied shrub layer found in many ash woods can, in the southern part of their range, provide suitable habitat conditions for dormice *Muscardinus avellanarius*, and is important for woodland birds. The alkaline bark of old ash (and elm where it still survives) supports important lichen species, particularly the Lobarion community.

Upland mixed ash woodland is found throughout upland England. The boundaries between this type and lowland mixed deciduous woodland may be unclear in places, for example in the Quantocks, because the two types form an ecological continuum determined by climate and soils. There are no precise data on the total extent of upland ash woods in England, but in the late 1980s the Nature Conservancy Council estimated the total extent of ancient semi-natural woodland of this type to be 40,000 - 50,000 ha in the UK. It has declined in area by about 30-40% over the last 50 years as a result of clearance, overgrazing and replanting with non-native species.

Potential climate change impacts

Cause	Consequence	Potential impacts
Increased mean temperatures		■ Decline of boreal and sub-boreal bryophyte and moss species at their range margins in the UK, especially in southern-most sites (Ellis 2012). ■ Potential breakdown in synchrony between species due to changes in the time of flushing, for example within food webs (Broadmeadow & Ray 2005, Ray, Morison & Broadmeadow 2010) and food availability (Masters *et al* 2005, Read *et al* 2009).
Drier summers	Drought Fire	■ Drought will lead to stress in drought sensitive tree species particularly birch and sycamore in the southern margins of the habitat's range, eventually changing tree species composition, with knock-on impacts on ground flora. ■ A decline and potential loss of sensitive ground flora and epiphytes, particularly ferns, bryophytes and lichens with oceanic distribution patterns (Ray, Morison & Broadmeadow 2010; Ellis 2012). ■ Increased tree stress, leading to greater susceptibility of trees to pests and diseases (Broadmeadow & Ray 2005). ■ There is potential for increased vulnerability of ground flora to drought in woodland where ash dieback has opened the canopy. This may be moderated by other tree species replacing ash in the canopy. ■ Broadleaved trees are relatively resistant to fire, but fires could result in localised changes in ground flora and understorey composition (Ray, Morison & Broadmeadow 2010), and could lead to localised loss of seedling regeneration and established saplings (Ray, Morison & Broadmeadow 2010).
Warmer winters	Fewer frosts	■ Improved winter survival of mammal pests such as deer and grey squirrel could lead to reduced regeneration and loss of ground flora. ■ Fewer frosts could lead to insufficient chilling to break Ash seed dormancy.
In combination		■ The creation of gaps in the canopy and a general reduction in competitive interactions in woodland impacted by ash dieback could exacerbate the threat from invasive native and non-native species.

Adaptation responses

Ash dieback has the potential to significantly change the structure and composition of upland mixed ash woodland. Adaptation to climate change should be built into and aligned with responses to the disease.

Many actions that aim to improve the resilience of ash woodland, for instance actions to reduce non-climatic pressures such as pests and invasive species, and improving the structural heterogeneity and species diversity of woodland, will promote adaptation to climate change and improve the resilience of woodland.

Some of the potential adaptation options for this habitat are outlined below.

- Reduce the impacts of non-climatic pressures through active management. These may include browsing damage from deer, sheep and other herbivores, pollution from agricultural spray drift, soil compaction and erosion, and the spread of invasive species such as Himalayan balsam *Impatiens glandulifera*.
- Avoid changes that impact on the hydrological functioning of the site.

- Allow natural woodland processes and/or woodland management to promote a diversity of age structure within woodlands. This may include retaining some undisturbed old growth stands, encouraging natural regeneration, allowing pockets of wind throw trees and deadwood, and creating a 'graduated' woodland edge (as opposed to a sharp boundary with neighbouring land uses).
- Promote through both natural regeneration and/or planting, a diversity of native tree species in the canopy, such as aspen, alder, rowan and small leaved lime. Take opportunities to include species or provenances with a more southerly distribution; for example small leaved lime. Ecological Site Classification can be used to assess site suitability and indicative future impacts of climate change.
- Identify any resistance to Chalara in the ash population and take measures to protect these trees and allow them to regenerate naturally.
- Aim to maintain large, old trees and the quantity of dead wood.
- Retain sycamore if its presence is not impacting on other aspects of the native flora or fauna, or if it is supporting species otherwise endangered by ash dieback.
- Aim to buffer sites by extending the woodland edge and, where appropriate, taking opportunities for new woodland creation nearby.
- Identify potential refugia where the direct impacts of climate change may be less than in the surrounding area. These could include north facing slopes and areas with more secure water supply (e.g. near spring lines or low lying areas closer to the water table) and places with relatively high rainfall. These areas should be protected from other pressures where possible.
- Develop contingency plans to deal with outbreaks of pests such as emerald ash borer *Agrilus planipennis*, diseases and the increased risk of major new disturbance events such as wildfires.
- Take positive steps in all woodland situations to increase the proportion and diversity of decaying wood throughout sites so as to ensure both resilience of dependent species, and the replenishment of woodland soils' organic content and hence capacity for moisture retention and provision of other essential ecological functions needed by trees and other species.

Mixed ash/alder woodland. Forest of Ae, Scotland. © Forestry Commission Picture Library

Relevant Countryside Stewardship options

WD1 Woodland Creation - maintenance payments

This option aims to support the successful establishment of newly created woodland that provides environmental and/or social benefits including:

- Supporting wildlife, particularly where new woodland links habitats or provides a protective buffer.
- Help reduce flood risk, improve water quality and prevent soil erosion.
- To create woodland that is resilient and can adapt to climate change.
- Landscape enhancement.

WD2 Woodland improvement

This option aims to change the woodland structure or management regime to improve biodiversity or enhance resilience to climate change. Dependent on the operation, multi-annual agreements will show a gradual restructuring or improvement in the condition of the woodland.

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Wet woodand. Ickburgh, Norfolk
© Mark Broadmeadow

5. Wet woodland

Climate change sensitivity: **Medium**

Introduction

Wet woodlands experience waterlogged conditions for at least part of the year, so are sensitive to changes in climatic conditions. Many of the tree species associated with wet woodland are expected to be relatively resilient to climate change (Gosling *et al* 2009, NEA 2010), but the nature of impacts will depend largely on how precipitation patterns change. In many instances, wet woodland is a successional habitat that will move towards dry woodland over time and reductions in summer rainfall and water tables are likely to hasten this process. Increases in the abstraction of water from catchments during dry periods will exacerbate the direct effects of climate change.

Much of our wet woodland has been lost or destroyed over recent decades due to clearances and land drainage for agricultural production, and it remains susceptible to changes in agricultural land use.

Increased river flooding may increase the value of wet woodland as a natural flood, erosion and water quality management tool, creating opportunities for habitat creation and retention.

Habitat Description

Wet woodland occurs on poorly drained or seasonally wet soils, usually with alder, birch and willow as the predominant tree species, but sometimes including ash, oak, and beech on the drier riparian areas. It is found on floodplains, as successional habitat on fens, mires and bogs, along streams and hill-side flushes, and in peaty hollows. These woodlands occur on a range of soil types, including nutrient-rich mineral soils and acid, nutrient-poor organic soils. The boundaries with dry woodland may be sharp or gradual and may change with time through succession, depending on the hydrological conditions and the treatment of the wood and its surrounding land. Therefore, wet woods frequently occur in a mosaic with other woodland habitat types such as mixed ash and oak woods and with open habitats such as fens.

Many alder woods are ancient and have a long history of coppice management which has determined their structure, and in some situations it appears that this practice has maintained alder as the dominant species and impeded succession to drier woodland communities. Other wet woodland may have developed through natural succession on open wetlands (sometimes following cessation of active management) and structurally are little influenced by direct forestry management.

Notable concentrations of wet woodland on fens occur in East Anglia, Shropshire and Cheshire, while hillside and plateau alder woods are more restricted to Wales, Cumbria and western Scotland. Fragments of ancient floodplain forest are rare, and the best examples are probably in the New Forest and northern Scotland. Bog woodlands of pine on bog are confined to Scotland, but fragments of birch bog woodland occur more widely in scattered stands across the UK.

Wet woodland combines elements of other ecosystems and as such can be important for many species groups. The high humidity favours bryophyte growth. A large number of invertebrates are associated with alder, birch and willow, including the Section 41 species, sallow guest beetle *Melanopion minimum* and jumping weevil *Rhynchaenus testaceus*. Even quite small seepages may support craneflies such as *Lipsothrix errans* and the endemic *Lipsothrix nervosa*. Dead wood within wet woodland is common, and its association with water provides specialised habitats not found in dry woodland types. The cranefly *Lipsothrix nigristigma*, for example, is associated with log jams in streams. Wet woodland provides cover and breeding sites for otters *Lutra lutra*. While few rare plant species depend on wet woodland, there may be relict species from the former open wetlands within wet woodlands, such as the marsh fern *Thelypteris palustris*.

Potential climate change impacts

Cause	Consequence	Potential impacts
Drier summers	Drought	■ Drying out of sites reliant on rainfall could lead to a change in the dominant tree species and conversion to drier woodland habitat types. The composition of ground flora is also likely to change.
Wetter winters		■ Potential colonisation of open ground habitat in the lower reaches of catchments fed by upland headwater tributaries (Ray *et al* 2010). ■ Long-term water-logging may lead to increased dominance of tree species such as alder and willow and localised changes in ground flora and understory composition.
Warmer winters	Fewer frost events	■ Increased survival of mammal pests such as deer species and grey squirrel *Sciurus carolinensis* resulting in more damage to thin barked trees and reduced regeneration, and an increased risk of colonisation by invasive non-native species. ■ A reduction in alder *Alnus glutinosa* dominance due to the impacts of *Phytophthora* spp (Ray *et al* 2010).
Increased frequency of extreme events	Summer and winter flooding	■ An increase in the frequency of extreme floods could result in the death of older trees and the development of scrubby stands. ■ Access to sites to undertake management may become increasingly difficult. ■ More frequent extreme events could create opportunities for restoring or creating wet woodland as a flood, erosion and water quality management tool.

Adaptation responses

Rainfall is likely to be the main cause of change in wet woodlands rather than temperature. At present, there is significant uncertainty in the climate projections for precipitation. Even if the current projections of drier summers and wetter winters prove to be accurate, the overall impact on wet woodlands is uncertain.

As with other woodland habitats, there are likely to be changes in both the abundance of the habitat and the composition of species within it. In certain sites reduced water availability will drive succession to drier woodland types such as beech and oak (especially English oak on heavier soils) or to scrub habitat, depending on soil depth, soil water holding capacity and the change in rainfall seasonality.

The management of water availability and levels will become increasingly important in catchments in the south and east of the country. The resilience of wet woodland may be increased by promoting structural and species diversity and the management of invasive species. New planting can reduce the vulnerability of existing sites though increasing patch size and providing a buffer to neighbouring land.

Some of the potential adaptation options for this habitat are outlined below:

- Reduce the impacts of other pressures such as pests and diseases, pollutants, over-grazing and development pressure. Reducing deer pressure, for example, allows more natural regeneration.
- Remove sources of nutrient enrichment by increasing the area of extensively managed land around the wetland and implementing good practice throughout the site's catchment.

- Where water supply is critical for the interest feature, consider actions that enable water tables to be artificially maintained during the spring and summer, including the use of artificial structures.
- Actively manage woodland to ensure structural heterogeneity and different age classes among canopy trees, for example through rotational coppicing.
- Accept and encourage a greater mix of native trees and shrubs within the canopy and shrub layer.
- Monitor and address potentially harmful invasive native and non-native species. This might include the use of surveillance to detect the arrival of species at an early stage (while they can still be eradicated) and identifying potential sources of invasive species in the surrounding area.
- Promote wet woodland as potential new green infrastructure in new developments and as part of larger wetland creation schemes.
- Where new planting is being considered:
    - prioritise areas with more secure water supply (e.g. spring lines or low lying areas closer to the water table) as they may represent potential refugia from the direct impacts of climate change;
    - consider the proximity to sources of invasive species when identifying locations, and avoid sites that could connect invasive pathways to areas of conservation interest;
    - give priority to making existing sites larger and reducing edge effects;
    - promote resilience through planting a range of tree species; options can be assessed using Ecological Site Classification.
- Where possible, identify opportunities to restore or create wet woodland habitats as part of flood management schemes within river floodplains. Within wet woodland, the retention of in-stream woody debris can help to enhance flood alleviation.
- Take positive steps in all woodland situations to increase the proportion and diversity of decaying wood throughout sites so as to ensure both resilience of dependent species and the replenishment of woodland soils' organic content and hence capacity for moisture retention and provision of other essential ecological functions needed by trees and other species.

Mature wet birch, alder riparian woodland, Crathes Castle, Aberdeenshire. © Forestry Commission/Isobel Cameron

Relevant Countryside Stewardship options

WD1 Woodland Creation - maintenance payments

This option aims to support the successful establishment of newly created woodland that provides environmental and/or social benefits including:

- Supporting wildlife, particularly where new woodland links habitats or provides a protective buffer.
- Help reduce flood risk, improve water quality and prevent soil erosion.
- To create woodland that is resilient and can adapt to climate change.
- Landscape enhancement.

WD2 Woodland improvement

This option aims to change the woodland structure or management regime to improve biodiversity or enhance resilience to climate change. Dependent on the operation, multi-annual agreements will show a gradual restructuring or improvement in the condition of the woodland.

Further information and advice

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Pollarded oak. Hatfield Forest SSSI, Essex
© Natural England/Peter Wakely

6. Wood pasture and parkland

Climate change vulnerability: **Low**

Introduction

The structure and composition of wood pasture and parkland is heavily influenced by past management. Two key wood pasture tree species, beech and common oak, are not generally regarded as being at risk across large areas of England (Berry, Onishi & Paterson 2012). However beech dominated wood pasture in the south of England will be increasingly vulnerable to drought, particularly on freely-draining soils and soils subject to seasonal water-logging. More generally, drought and an increased frequency of storms pose a threat to veteran trees, which are a distinctive feature of much wood pasture and parkland. Due to the modified nature of the habitat, its persistence will depend on ensuring appropriate management decisions, such as replanting specimen trees, the choice of tree species (including the use of non-native species), and the level of grazing.

Habitat Description

Wood pastures and parkland are the products of historic land management systems and designed landscapes, and represent a vegetation structure rather than a particular plant community. Typically, this structure consists of large, open-grown or high forest trees (often pollards) at various densities, in a matrix of grazed grassland, heathland and/or woodland floras. They have been managed by a long-established tradition of grazing, allowing the survival of multiple generations of trees, characteristically with at least some veteran trees or shrubs (Bergmeier *et al* 2010). They frequently represent the best sites in England for old-growth features and deadwood, supporting a wide range of specialist fungi and invertebrate species (Webb, Drewitt & Measures 2011).

The tree and shrub component will have been managed over centuries, but in a diversity of ways and can occur as scattered individuals, small groups, or as more or less complete canopy cover. Depending on the degree of canopy cover, other semi-natural habitats, including grassland, heath and scrub may occur in mosaic with woodland communities. While oak, beech, alder, birch, ash, hawthorn, hazel or pine are often dominant, a wide range of other tree and shrub species may occur as part of wood-pasture systems. Parkland differs from wood pasture in that deliberate planting, often with non-native species into a designed landscape, represents a significant component. Parklands are frequently designated for their historic and landscape value.

Lowland wood-pastures and parkland are most commonly associated with oak - bracken - bramble woodland (W10), beech - bramble woodland (W14), beech - wavy hair grass woodland (W15), and oak - birch - wavy hair grass woodland (W16), although others may occur. Upland examples may show more resemblance to W11 (sessile oak - downy birch - wood sorrel) and W17 (sessile oak - downy birch - greater fork moss) woodland types. In addition, the more open wood pastures and parkland may include various scrub, heathland, improved and unimproved grassland NVC communities.

This habitat is most common in lowland southern England. These sites are often of national historic, cultural and landscape importance, for example in the New Forest. This habitat also occurs in the uplands, but is less understood than that in the lowlands.

Potential climate change impacts

Cause	Consequence	Potential impacts
Hotter summers		■ Increased sun-scorch leading to bark-death of beech. ■ Reduced generation time of insect pests such as Oak pinhole borer *Platypus cylindrus* and Oak buprestid *Agrilus pannonicus* (Read *et al* 2009).
Warmer winters	Fewer frost events	■ Greater survival of tree pests, such as grey squirrel and species of deer, resulting in increased browsing and grazing pressure and reduced regeneration. (Read *et al* 2009). ■ Greater over-wintering survival of insect pests leading to increased abundance and pressure (Ray, Morison & Broadmeadow 2010).
Changed seasonal rainfall		■ Trees rely on mycorrhizal fungi to help resist pathogens and provide nutrients. These fungi may be susceptible to drought, water-logging or changes in soil temperature (Lonsdale & Gibbs, 2002).
Drier summers	Drought Greater risk of fire	■ Increased loss of mature and veteran trees and loss of associated saproxylic invertebrates, lichens and fungi. ■ Beech is particularly vulnerable because of shallow rooting on soils subject to water-logging. This may be exacerbated in wood pasture and parkland compared to closed canopy woodland due to increased transpiration rates (Berry, Onishi & Paterson 2012). ■ Changes in ground flora composition are most likely if canopy trees die. ■ Vulnerability will differ according to local climate, soils and catchment hydrology. ■ Premature death of mature and veteran trees.
Wetter Winters	Raised winter water tables and increased risk of flooding	■ There is an increased likelihood of wind throw if tree-root depth becomes restricted by increased rainfall and water-logging on sites with impeded drainage (Ray, Morison & Broadmeadow, 2010). ■ The impact of flooding will differ between species, with, for example, willow and alder able to withstand flooding longer than other species.
Increased frequency of extreme events	High winds Extremes of soil temperature and moisture Drought	■ Increased frequency of wind throw, leading to the loss of mature and veteran trees and an increased break up of large, unstable crowns in veteran trees, particularly those that have fallen out of the pollard cycle. ■ Loss of veteran trees leading to a loss of specialist species associated with veteran tree habitat (primarily fungi, invertebrates and lichens), although insect larvae within trees may be protected from extreme conditions. ■ Greater incidence of environmental stress, resulting in increased susceptibility to other pressures such as pests and disease. ■ See drier summers above. Note that the impacts of a dry summer are exacerbated if it follows a dry winter, meaning that the summer starts with a lower soil moisture content.
In combination		■ Increasing prevalence and range expansion of pests such as Oak processionary moth *Thaumetopoea processionea*, Gypsy moth *Lymantria dispar* and pathogens such as *Phytophora* (Read *et al* 2009), leading to the potential loss or significant reduction in key species including oak, beech and ash.

Adaptation responses

The heavy influence of historic and current management on the structure, function and condition of wood pasture and parkland provides flexibility in designing appropriate adaptation and also managing change. However, when making management decisions, consideration of the landscape and cultural value of the site will normally be necessary, particularly when dealing with historic parklands and other 'designed' landscapes.

An important value of veteran trees, which are often the main feature of wood-pasture and parkland, is the ecological continuity in the dead and decaying wood they contain. Consequently, adaptation is likely to focus on actions that promote the longevity of existing mature and veteran trees and ensuring that new generations of appropriate species and genotypes are planted to replace trees as they are lost (and preferably before they are lost), thereby ensuring the continuing structural heterogeneity of sites. Management of younger trees to encourage the development of dead and decaying wood to fill the gap between veterans and younger trees will also be important.

Flexibility of grazing and the development of effective contingency plans to respond to increased climatic variation and an increase in extreme events will also be important adaptive actions.

Some of the potential adaptation options for this habitat are outlined below.

- Where possible, reduce the impacts of other non-climatic pressures, such as pests and diseases, pollutants and development pressures. Adjust grazing levels according to environmental conditions to avoid over and under-grazing and compaction.
- Maintain pasture rather than arable land use under the trees to avoid adverse impacts on root systems.
- Protect mature and veteran trees from over and under-grazing.
- Ensure adequate regeneration and replanting to establish new generations of trees to replace individuals and species that are lost or likely to be lost under climate change. These new trees should be protected from grazing and competition, and should be managed to provide appropriate conditions for saproxylic invertebrates (i.e. decaying wood). Young trees may be protected from grazing and browsing by fallen branches and dead wood, giving an additional reason for retaining dead wood.
- Management of veteran trees to reduce the likelihood of catastrophic failure, for example by reducing the crown to reduce the sail effect in high winds and improving the protection for individual veteran trees. The benefits of undertaking crown works on veteran trees need to be weighed against the risks, and the guidance of a suitably qualified arboriculturalist can provide advice.
- Consider introducing or reinstating pollarding to semi-mature trees less vulnerable to storms and drought, to accelerate the development of veteran tree features and niches for specialist fungi and invertebrates, but consider the risk from crown works, as outlined above. Pollarding to reduce crown density can also help to reduce the possibility of catastrophic failure. The presence of ash dieback should be taken into account when management, pollarding or re-pollarding of ash trees is being considered.
- Ensure that standing and fallen deadwood is not cut up and is only moved if absolutely necessary, as it represents a key niche requirement for many specialist species.
- Trees blown over by storms may grow new stems if the roots are undamaged or the horizontal trunk remains connected to the root system, if left uncut and not 'tidied up' or removed from the site, where there are no safety concerns.

- Develop fire management plans, especially in wood pasture and parkland where the threat of fire is thought to be high, such as those with a bracken-rich or heather understorey. Introduce grazing animals, or other appropriate management, to reduce the amount of litter in sites with a lot of bracken.
- Develop contingency plans for outbreaks of new pests and diseases and other extreme events.
- When planting, understand soil type and heterogeneity across a site to better match species to planting location, including a consideration of the likely direction of climate change. Species choice is particularly challenging for future veteran trees, given the long planning horizon.
- Consider selecting more drought-tolerant species, or provenance from the southern parts of a species' range, when replanting. Where possible, select species whose decay fungi and mechanisms create similar conditions to existing species. For example, sweet chestnut grows faster than oak, but has similar heartwood and rots in a similar way, so some of the species associated with oak will find sweet chestnut a suitable alternative host.
- Consider planting non-native/exotic species (e.g. cedar, redwood), only where these are consistent with landscape character and designated/designed landscapes.
- New trees need to be established with sufficient space to grow with open crowns, if they are to provide habitat niches for those species dependent on the specific conditions in the trees, including many lichen species.
- Buffer and expand existing sites through planting or by encouraging natural regeneration of open grown trees.
- Encourage the establishment of veteran features in mature trees through veteranisation[2] techniques.

2 Intentional damage to younger trees can speed up the process of creating habitats, such as rot holes and dead wood, which older trees offer.

Veteran oak, Calke Abbey, Derbyshire. © Natural England/Paul Lacey

Relevant Countryside Stewardship options

WD4 Maintenance of wood pasture and parkland

WD5 Restoration of wood pasture and parkland

The aim of these options is to maintain, restore and enhance the wildlife, historic and landscape character of parkland and wood pasture. The ongoing commitments are the protection and management of the trees and the continuation of livestock grazing. The options will often require the preparation of a management plan that will form the basis of the agreement. Capital items for tree management may also be used with this option.

WD6 Creation of wood pasture

This option is used to create wood pasture on sites that are known to have been wood pasture previously, or on sites adjacent to or linking existing areas of wood pasture. The preferred method of creation will be by careful and flexible grazing management to allow trees and shrubs to develop by natural regeneration. In some cases is might be necessary to sow a specified grass seed mixture, and in most cases will it be necessary to ensure the establishment of the next generation of trees by planting new ones.

Further information and advice

Natural England **Veteran Trees: A guide to good management** (IN13).

Forestry Commission Scotland (2009) **Management of ancient wood pasture**.

The Ancient Tree Forum.

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Bramley apple orchard, Cambridgeshire.
© Chris Knights (rspb-images.com)

7. Traditional orchards

Climate change sensitivity: **Low**

Introduction

The species composition and structure of traditional orchards are determined by management, which provides a mechanism to respond to the impacts of climate change. Orchards are sensitive to the impacts of drought, warmer winters, and the potential for more frequent storms, but these impacts can be mitigated by changes in management and appropriate replacement and replanting. Although it may be possible, in the long term, to plant new varieties in response to climate change, fruit trees live anywhere from 70 to 200 years, or more, so there is a risk of existing trees either dying or being replaced because they are not commercially viable, before any new planting matures enough to create replacement habitat. This would also have a detrimental impact on the genetic conservation of rare varieties. Indirect impacts, such as changes to the economics of orchards and a shift from traditional crops to new ones that require more intensive management, may pose a greater threat.

Habitat Description

Traditional orchards are defined as groups of fruit and nut trees planted on vigorous rootstocks at low densities in permanent grassland orchards and managed in a low-intensity way. This contrasts with orchards managed intensively for fruit production which often use short-lived, high-density, dwarf or bush fruit trees, and are characterised by the input of chemicals such as pesticides and inorganic fertilisers, and frequent mowing of the orchard floor rather than grazing or cutting for hay. Habitat structure, rather than vegetation type, topography or soils, is the defining feature of orchard habitats.

Traditional orchards are structurally and ecologically similar to wood-pasture and parkland, with open-grown trees set in herbaceous vegetation. They are distinguished from this habitat by the species of tree (being primarily of the family *Rosaceae*), the generally denser arrangement of the trees, and the small size of individual habitat patches.

Management of the trees is the other main feature distinguishing traditional orchards from wood-pasture and parkland. Trees in traditional orchards are, or were, grown for fruit and nut production, usually achieved through practices such as grafting and pruning; whereas the main product from trees in wood-pastures and parkland has been timber, mostly derived from pollarding or selective felling, although beech mast, acorns and chestnuts are all products of wood-pasture systems.

Grazing or cutting the understorey is integral to orchard management. The presence of scrub, mostly in the form of hedgerows on the site boundaries, or sometimes, especially in unmanaged orchards, among the orchard trees, is analogous to the frequent occurrence of scrub in wood-pasture and parkland, and plays a similar ecological role. Ponds and other wetland features are often present, being used now or in the past for watering livestock.

Traditional orchards are found throughout the lowlands of England, although there are concentrations in Kent, Cambridgeshire, Somerset, Herefordshire, Worcestershire and Gloucestershire. The estimated area in England is 17,000 ha.

Potential climate change impacts

Cause	Consequence	Potential impacts
Drier summers	Drought	■ A reduction in available moisture during the growing season can lead to root stress, possible defoliation, premature fruit drop, or low fruit size.
Warmer summers	Warmer temperatures and a longer growing season.	■ Temperatures constantly in the high 20°Cs, when associated with drier conditions, can cause heat stress (see above). Continued warm autumn weather with adequate moisture may compensate for some of these effects. ■ Hotter, drier summers may see an increase in the occurrence of powdery mildew *Podosphera leucotrica*, especially in the south west. ■ Fire blight *Erwinia amylovora* bacterium favours warm, humid conditions and so could become more widespread in wet springs. ■ Warmer summers may result in increased pest damage, where pest populations increase or new pests arrive from overseas. ■ Warmer conditions could lead to traditional orchard fruit species being replaced by fruit currently grown in more southern locations, such as peaches, that require more intensive management and which probably don't support the same suite of wood decay species e.g. noble chafer *Gnorimus nobilis* and some lichens. ■ Warmer, drier summers may change the composition of species-rich swards, as with other grassland.
Warmer winters	Fewer frost events	■ Fewer frosts will result in greater over-wintering survival of insect pests, leading to higher populations and greater pressure on trees. ■ Apple trees need several weeks of relatively cold weather to complete dormancy. Warmer average winter temperatures will give inadequate periods of vernalisation[3]. This will affect different apple varieties in different ways: some may flower too early, risking damage from late frosts; some may flower at a different time from their pollinator; and varieties requiring a longer dormancy may develop 'blind buds' that fail to develop in spring. ■ Sporadic flowering over a prolonged period may lead to pollination problems. ■ Poor leaf quality at flowering time will lead to poor fruit set.
Wetter winters		■ Wet and warm weather from autumn to spring could increase the risk of scab *Venturia inaequalis*. ■ Wet soil conditions will increase the risk of wind throw in windy weather. ■ Prolonged wet soil conditions with poor drainage will increase the risk of tree death from water-logging, or crown rot caused by *Phytophthora spp*.
Increased frequency of extreme events	Heat waves Extremes of soil temperature and moisture Increased frequency of storms	■ Some varieties of apple can suffer from sun scorch in hot weather. ■ High winds, coupled with water-logged soil, may increase the frequency of wind throw, leading to the loss of mature and veteran trees. ■ Severe storms can increase the spread of pests and diseases such as fire blight.
In combination		■ General disruption of the natural yearly fruit tree cycle may increase biennial cropping. Extreme weather such as warm springs followed by late frosts, unseasonal wet weather and hail storms can have negative impacts on pollination and fruit set. ■ Warmth-loving invertebrates associated with dead wood, possibly including the rare noble chafer beetle Gnorimus nobilis may spread northwards, but could be lost in the south. ■ Bird species that nest in orchards, such as redstart *Phoenicurus phoenicurus* and woodpeckers, may be lost, while other species, including Wryneck *Jynx torquilla* and Hoopoe *Upupa epops*, may become established. ■ Current winter species, including redwing *Turdus iliacus* and fieldfare *Turdus pilaris*, may no longer visit. Other species may start wintering here with warmer winters, e.g. blackcap *Sylvia atricapilla* have started wintering in south east England and may spread (they feed on mistletoe berries and may be responsible for increasing the spread of mistletoe in the south east).

3 The subjection of seeds or seedlings to low temperature in order to hasten plant development and flowering.

Adaptation responses

The influence of historic and current management on the structure, function and condition of traditional orchards provides a high degree of flexibility in designing appropriate adaptation strategies and managing change. Continuing, or reintroducing, low input active management of traditional orchards is a key adaptive response. Increasing the species and structural diversity of orchards at a site and landscape-scale will also reduce vulnerability. Selection of the appropriate species and cultivars for the site will also play a role in future proofing orchards against climate change.

Some of the potential adaptation options for this habitat are outlined below:

- Ensure continued extensive management of orchards, with little or no agrochemical input, and using grazing rather than machinery to manage the understorey.
- Adjust grazing levels according to environmental conditions to avoid under and over-grazing and compaction.
- Minimise soil erosion by grassing-down alleyways. Alleyways are a feature of bush orchards rather than traditional orchards, which have permanent grass swards.
- Increase the age structure and variety of species within orchards through management and replanting.
- Consider selecting more drought-tolerant species, or provenance from the southern part of a species' range when replanting. This may not always be possible, for example if no cider varieties are able to be grown, then the cider industry would have to import fruit and therefore have no reason to conserve orchards.
- Select varieties with lower dormancy requirements. Many late-flowering, late-maturing varieties, especially cider apples, require greater cold vernalisation than early flowering varieties. This may conflict with the genetic conservation of rare, localised varieties.
- Ensure that all planting material complies with the EU plant passport scheme, which includes a requirement for freedom from fire blight.
- Establish windbreaks for shelter prior to planting trees and use strong tree support systems on exposed sites.
- Manage mature trees to reduce the threat of wind rock and wind throw. For example, encourage sustainable mistletoe harvesting from trees exposed to high winds.
- Plan for changes in the availability and demand for water by, for example, increasing on-farm water storage capacity or installing a trickle irrigation system.
- Ensure the continued presence of decaying wood within live trees by prolonging the life of old trees. Retain dead wood, both on the trees and where it falls.
- Develop contingency plans for outbreaks of new pests and diseases and other extreme events.
- Ensure regular monitoring of pests and diseases and adhere to best practice in integrated pest management.
- Consider the use of natural products and biocontrol agents for mildew control, and select resistant varieties in new planting.

Apple blossom. © Natural England/Ian Dalgleish

Relevant Countryside Stewardship options

BE4 Maintenance of traditional orchards

This option aims to maintain existing traditional orchards that are generally in good condition and that are being managed extensively for wildlife and historic landscape benefits, or to restore degraded orchards by re-planting traditional varieties of orchard trees to return tree numbers to an appropriate level. Ongoing management will require suitable livestock grazing and the protection and maintenance of the trees.

BE5 Creation of traditional orchards

This option aims to re-create orchards on sites that are known to have previously been orchard sites, sites where less than one-third of the original stations are occupied by trees over 25 years old, and sites where creation extends, links or buffers existing areas of a traditional orchard.

Further information and advice

Natural England has produced a number of publications about orchards, including series of Technical Information Notes. These can be found **here**.

Farming Futures Climate Change Series Fact Sheet 16 - **Focus on apple and pear orchards**.

The **Orchard Network**. A partnership of organisations working together for the conservation of traditional orchards as a wildlife habitat.

JNCC (2008) UK BAP habitat description **Traditional Orchards**.

Blackthorn hedge in blosom.
© Natural England/Allan Drewitt

8. Hedgerows

Climate Change Sensitivity: **Low**

Introduction

By their nature, hedgerows are linear, and consequently are vulnerable to edge effects. Drought and storms are therefore likely to have a greater impact on hedgerow trees than on blocks of woodland. Hedgerows are also vulnerable to changes in the use and management of adjacent land, so any climate change driven intensification of agriculture could have impacts, both on how they are managed and from off-site impacts such as pesticide drift.

Habitat Description

A hedgerow is defined as any boundary line of trees or shrubs over 20m long and less than 5m wide, and where any gaps between the trees or shrub species are less than 20m wide (Bickmore 2002). Any bank, wall, ditch or tree within 2m of the centre of the hedgerow is considered to be part of the hedgerow habitat, as is the herbaceous vegetation within 2m of the centre of the hedgerow.

The original hedgerow Biodiversity Action Plan (BAP) definition was confined to 'ancient and/or species rich' hedges, however, it has now been expanded to include all hedgerows consisting predominantly (at least 80%) of at least one native woody species of tree or shrub. Climbing plants such as honeysuckle and bramble are recognised as integral to many hedgerows, but are not included in the definition of woody species. The definition is limited to boundary lines of trees or shrubs, and excludes banks or walls without woody shrubs on top of them.

Hedgerows are found across the country, but are concentrated in the lowlands. The proportion of trees within hedges increases to the west and north, while in the south-east hedges are associated with larger fields and have fewer trees. The species composition and management of hedges is often regionally distinctive. For example, in Devon and Cornwall, hedges are characteristically found on earth, stone or turf-faced banks, whereas beech hedges are common on Exmoor and the Quantocks, and Damson hedges are characteristic of Herefordshire. These distinctive hedgerow types often make an important contribution to local landscape character.

There are over 550,00km of hedgerow in England, with over 400,000km being actively managed (Carey *et al* 2008).

Potential climate change impacts

Cause	Consequence	Potential impacts
Increased annual average temperature	Longer growing season	■ Increased growth, leading to greater management requirements and an enhanced threat of abandonment. ■ Increased shading of hedgerow herbaceous flora. ■ Changing composition of wildlife in hedgerows.
Warmer winters	Fewer frost events	■ The winter chill requirements of berry species may not be met. Reduced bud, flower and fruit production will affect food resources for wildlife.
Drier summers	Drought	■ Increased mortality and die-back of certain hedgerow tree species, such as beech in the south-east of its range. Drought stress will increase trees susceptibility to pests and diseases.
Wetter winters	Flooding Water-logging of soils Erosion	■ Woody species exposed to prolonged flooding in the growing season will be at risk of dying. ■ The winter trimming of hedgerows will become more difficult in some areas due to wet ground conditions. Winter trimming is preferred to autumn trimming to ensure berries and fruits are available for birds and other species. ■ Wet soil conditions could cause damage to soil structure, leading to increased die-back of hedgerow trees.
Increase in storm frequency	High winds	■ Loss of mature and veteran hedgerow trees.
In combination	Changing patterns of agriculture	■ Intensification of adjacent land use leading to increased offsite impacts such as pesticide drift and nutrient enrichment. ■ Re-intensification leading to a reduction in the use of buffer strips and margins to protect adjacent hedges.
	Increased occurrence of insect pests and pathogens	■ Potential loss or significant reduction in populations of key hedgerow tree species.

Adaptation responses

The current definition of hedgerows includes recently planted and species poor hedges, as well as species rich and ancient types. This, and the regional differences in species composition and management practices, means that appropriate adaptation actions are likely to vary according to hedge type and location.

In the majority of cases, reducing the impact of adjacent land uses through effective buffering will remain a key response, as will some form of management to prevent hedges developing into lines of trees (although lines of trees may have benefits in some circumstances, including providing shade in a warmer climate and acting as windbreak).

When planting, restocking or filling gaps in hedges, consideration should be given to using a diverse range of species, particularly those that are adapted to a wide range of climatic conditions. Accepting and encouraging changes in the composition and structure of hedges will increasingly become a necessary element of ensuring that hedges remain resilient to climate change. Change will need to be undertaken within the context of local landscape character, with gradual rather than transformational change promoted.

Hedgerows may provide opportunities for some species to disperse across the landscape, increasing the potential to colonise newly suitable locations, both locally and nationally. It should not however be assumed that all, or even most, characteristic woodland species will use or spread along hedgerows – for example, ancient woodland indicator plant species colonise new sites very slowly and the microclimate of a hedge is typically lighter and more prone to fluctuations in temperature than the interior of a woodland.

Some of the potential adaptation options for this habitat are outlined below:

- The most important response to climate change is likely to be effective buffering against the impact of adjacent land uses, through for example the use of grass, uncultivated or low intensity margins, and fencing off livestock. This will become increasingly important whether or not there is an intensification of adjacent land use, as trees stressed by climatic factors such as drought or water-logging are more susceptible to other pressures.
- Regeneration of hedgerow trees and shrubs can be promoted through the management of grazing mammals and vigorous weed species, to promote a greater range of age classes.
- Maintenance of a diverse range of hedgerow structures through appropriate management, ranging from hedgerows that grade from tall scrub, with plentiful side shoots and foliage in the summer, to well-developed shrubs and tall sward grassland with herbs. Aim for a gradual gradation between the two habitats; the wider and more varied the structure the better.
- When establishing new hedges, aim to provide links to the existing hedgerow network and patches of semi-natural habitat in order to promote the movement of species through the landscape.
- When planting or restocking, aim to diversify the range of species and select species and provenances adapted to a wider range of climatic conditions. Where hedgerows contain tree species susceptible to climate change, consider restocking with more resilient species to establish the next generation of hedgerow trees.

Planting up gaps in a hedge. © Natural England/Peter Roworth

Relevant Countryside Stewardship options

TBE3 Management of hedgerows

This option aims to increase blossom availability for invertebrates; provide a vital source of food for over-wintering birds by allowing fruit and berries to ripen; and improve the structure and longevity of hedgerows.

BN5 Hedgerow laying

This option aims to rejuvenate or restore hedgerows by laying to achieve a continuous length of hedge.

BN6 Hedgerow coppicing

This option aims to rejuvenate or restore hedgerows by coppicing to achieve a continuous length of hedge.

BN7 Hedgerow gapping up

This option aims to rejuvenate or restore hedgerows by gapping-up to achieve a continuous length of hedge.

BN8 Hedgerow supplement - casting up

This option aims to replace slipped soil and re-profile earth banks when a hedgerow is being layed or coppiced.

BN9 Hedgerow supplement - substantial pre-work

This option aims to ensure that hedge rejuvenation or restoration can be completed where a hedge is on a particularly difficult site or where substantial extra work is required.

BN10 Hedgerow supplement - top binding and staking

This option aims to strengthen laid hedges by top binding and staking.

Further information and advice

Hedgelink is a partnership that brings together people and organisations interested in hedgerows to share knowledge and ideas, and to work with farmers and other land managers to conserve and enhance hedgerows.

Natural England (2017) **Countryside hedgerows: protection and management**. Important hedgerows (as defined in the Regulations) are protected from removal (up-rooting or otherwise destroying) by the Hedgerows Regulations 1997. Various criteria specified in the Regulations are used to identify hedgerows important for wildlife, landscape or historic reasons.

Council for the Protection of Rural England **Hedgerow resources**.

JNCC (2008) UK BAP habitat description **Hedgerows**.

Key evidence documents

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Conservation headland. Hope under Dinmore, Herefordshire
© Natural England/Peter Wakely

9. Arable field margins

Climate Change Sensitivity: **Low**

Introduction

The vulnerability of arable field margins to climate change is most likely to arise from changes in land use and agricultural practices. These may change in response to climate changes at both the local and global level, often driven by economic factors. Changes in the distribution and scale of arable production across the country represent both a threat and an opportunity for arable field margins.

The direct impacts of climate change are likely to be less important in the short to medium term.

Habitat Description

Arable field margins are herbaceous strips or blocks around arable fields that are managed to provide benefits for wildlife or to reduce water and soil run-off into water courses. Where they are managed for wildlife they are classed as a priority habitat. Arable field margins are usually sited on the outer 2-12m margin of the arable field but some can extend further into the field. The limit of arable field margin priority habitat is defined by the extent of any management undertaken specifically to benefit wildlife.

Arable field margins include cultivated, low-input margins; margins sown to provide seed for wild birds; margins sown with wild flowers or agricultural legumes and managed to provide pollen and nectar resources for invertebrates; and margins providing permanent grass strips with mixtures of tussocky and fine-leaved grasses. Areas of grass established as cross-compliance requirements are excluded from this definition, but all other strips of grassland created by sowing or natural regeneration, such as field margins or beetle banks, are included.

Arable field margins occur across much of lowland England in both arable and mixed (arable and livestock) farmland. Targeted habitat support for farmland birds, arable plants and other farmland biodiversity through government initiatives such as Environmental Stewardship and Countryside Stewardship has encouraged farmers and landowners to create arable field margins on their land. The field margins with the greatest diversity of arable plants are generally found in the Southern and Eastern counties (Walker *et al* 2006). There are just over 100,000 hectares of arable field margins across England. Most have been developed since the mid-1990s when incentive payments to create them first became available.

Potential climate change impacts

Cause	Consequence	Potential impacts
Higher average temperatures	Longer growing season Increase in pests and diseases	■ An expansion of arable agriculture in the north and west of England at the expense of pasture could create opportunities for new arable field margins. Changes in the growing season will increase the likelihood of phenotypic mismatch between flowering plants and their pollinators and those species that rely on them for nectar and food (Memmott *et al* 2007, 2008). ■ An increase in agricultural use of summer insecticides could reduce insect numbers and pollination.
Drier summers		■ Drier conditions could lead to changes to community composition, with increases in plants such as Alexanders *Smyrnium olusatrum*, common cudweed *Filago vulgaris*, asparagus *Asparagus officinalis*, dwarf mallow *Malva neglecta*, small-flowered crane's-bill *Geranium pusillum*, and meadow brome *Bromus commutatus* (Mirchell *et al* 2007). ■ An increase in the area of bare ground. ■ An increased risk of dieback in drought prone locations.
In combination		■ The introduction of new crops, with associated changes to management, could alter the area and type of field margins. Depending on market conditions and environmental incentives, some areas could see more intensification.

Adaptation responses

Maintaining or expanding the area of land available for margins is likely to be the most effective adaptation response, although this would need to be considered within the wider context and the best use of resources. The potential expansion of arable cropping into some areas of the west and north could assist this, but changes to global food supply, national food security issues and other pressures on land could make less land available overall for conservation.

The protection of margins from chemical inputs from adjacent cropped areas will remain a key measure to ensure their ongoing resilience to climate change.

Microclimates may vary considerably and lower temperatures resulting from shading, e.g. by hedges or slopes, could help to maintain some species *in situ*.

Field margins are likely to play a role in allowing some species to move within a landscape and find new locations locally or as part of a larger-scale change in distributions. There are some caveats to this, in that some species have limited mobility, and field margin habitats will not be suitable for others. However, as we move towards a more connected landscape-scale view of agri-environment and other land use interventions, we are likely to see more specific and tailored use of field margin habitat to facilitate suitable mobilisation corridors.

Some of the potential adaptation options for this habitat are outlined below.

- Maintain or expand the area of land available for arable field margins.
- Ensure that margins are protected from agricultural inputs to adjacent crops.
- Where possible, locate margins in a range of locations to provide variety of aspect, soil type and shading.
- Maximise the diversity of margins to provide a range of habitats and to assist in the movement of species through the landscape.

- Select the most appropriate management options for specific objectives. For example, uncropped cultivated margins have been demonstrated to be the most suitable option for arable plants, exhibiting the widest diversity of annuals, perennials, grasses, forbs (non-woody broad-leaved plants other than grass), and spring and autumn germinating species (Still and Byfield, 2007), while tailored sown mixes deliver the greatest benefit for farmland birds.
- In planted margins, tailoring the diversity of flowering species to ensure the continued provision of pollen and nectar throughout the extended season.
- In planted margins, include species and cultivars that are able to tolerate and flower under hotter, drier summers.

Arable margin © Nick Milton (rspb-images.com)

Relevant Countryside Stewardship options

The following Countryside Stewardship options may help with achieving some of the above adaptation actions:

SW1 4-6m Buffer strip on cultivated land

These low intensity grass buffer strips are established by sowing and can be used for a wide variety of purposes such as creating new habitat and protecting existing ones and capturing surface water run-off.

AB8 Flower-rich margins and plots

This option creates a flower-rich grass margin alongside arable cropping. The strip is managed by a programme of sequential cutting to provide habitat and foraging sites for insects and wild birds.

AB9 Winter bird food

This option is a sown mix of cereals and legumes and provides important food resources for farmland birds, especially in winter on arable land and mixed farms. The aim is to maximise the production of small seeds suitable as bird food in either annual or annual/biennial mixtures, whilst also providing a source of invertebrates for birds.

AB1 Nectar Flower mix

This option aims to boost the availability of essential food sources for a range of nectar-feeding insects, including butterflies and bumblebees through the planting mix of at least four nectar-rich plants (e.g. red clover, alsike clover, bird's-foot-trefoil, sainfoin, musk mallow, black knapweed). It provides valuable benefits to wildlife at a landscape scale and is ideally suited to larger blocks and small fields.

AB3 Beetle banks

Beetle banks are raised tussocky grass banks, between 3m and 5m wide that run from one side of a field to the other, whilst still allowing the field to be farmed. They provide habitat for ground nesting birds, small mammals and insects including those that feed on crop pests.

EF10, HF14 Unharvested, fertiliser free conservation headlands

AB10 Unharvested cereal headland

This option consists of a 6-24m wide cereal headland along the edge of an arable crop with no fertiliser and restricted herbicide and insecticide regimes. It provides an important food supply for birds, and habitat for arable plants and insects, within any arable field during the cropping year.

AB11 Cultivated areas for arable plants

An arable field margin is cultivated annually in either spring or autumn to provide a fine surface ideal for seed germination. These margins will provide beneficial management for rare arable plants, insects and foraging sites for seed-eating birds.

Further information and advice

JNCC (2008) UK BAP habitat description **Arable Field Margins**.

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The River Avon at Ibsley, Hampshire
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10. Rivers and streams

Climate Change Sensitivity: **High**

Introduction

Climate change is predicted to bring about a range of changes to environmental conditions in our rivers and streams, including shifts in thermal regimes, flow regimes and associated geomorphological processes, and chemical regimes. Some of these changes are already happening and are likely to intensify. The patterns and behaviours of the wildlife associated with our rivers and streams will change as a result. A range of measures are required to help our rivers and streams adapt to these changes.

If, as projected, we get milder winters and hotter summers, the changes in water temperature will impact on a wide range of river species adapted to cool water environments, including plants, invertebrates and fish. Species at particular risk include Atlantic salmon *Salmo salar* and the freshwater pearl mussel *Margaritifera margaritifera*.

A consistent pattern in climate change projections is for a decrease in mean summer rainfall, which is likely to increase the frequency and intensity of droughts. This will place riverine biota at greater risk from low flows, poor water quality, and reduced habitat space (area and depth). This could lead to increased competition and predation, thermal stress, siltation (due to reduced flushing), increased effluent pollution, and reduced dissolved oxygen levels in both sediments and overlying water. The species likely to suffer the most are those that are adapted to cool, fast-flowing waters and those that have poor powers of re-colonisation, such as those without aerial or drought-resistant life stages. Low flows could be exacerbated by increased abstraction during times of warm, dry weather.

Increases in flood magnitude and frequency will have both positive and negative effects. On one hand they could help rivers to reshape and restore themselves following historical physical modifications that have degraded riverine habitats. Conversely, local increases in flood risk to people and property may result in further conventional flood defence activity such as channelisation, dredging, embankments, and hard bank protection, involving further habitat damage. There is also the possibility that populations of some threatened species, such as freshwater pearl mussel, may be washed out by the scouring forces of extreme floods.

Projected increases in extreme rainfall events will increase the energy of catchment run-off, potentially generating enhanced loads of fine sediment and diffuse pollutants, particularly nutrients. Siltation and nutrient enrichment are key impacts on riverine biota, smothering coarse substrates and generating excessive growth of benthic and planktonic algae. This leads to declines in the many species dependent on clean, coarse sediments (e.g. salmonids and many benthic invertebrate species) and of species adapted to low nutrient and well-oxygenated conditions (e.g. freshwater pearl mussel, Atlantic salmon, and many stonefly species). Increased scour in rivers may partly offset increased pollutant loads by transporting pollutants downstream more effectively.

River systems are under threat from a wide range of non-native species, and some of these will have a larger potential range as a result of climatic warming across England. Many of these species originate from Eastern Europe and have already spread into western mainland Europe via a number of routes, most recently the Rhine-Danube canal, and some, such as the so-called 'killer shrimp' *Dikerogammarus villosus*, have recently made their way to the UK.

Habitat Description

This section provides a short summary of how rivers and stream habitats are shaped and how they function. A fuller description is provided in Mainstone *et al* (2016).

There is very wide variation in this broad habitat type, ranging from intermittent and perennial headwater streams to large rivers, and from cool, energetic upland conditions to warm, sluggish lowland examples. The nature of the catchment fundamentally affects the type of rivers and streams it supports. Catchments with more permeable geology generate rivers with high base flows and relatively low peak flows, whereas rivers with less permeable geology generate 'flashy' rivers with low natural base flows and high peak flows. Catchment geology also dictates water chemistry characteristics, from hard, alkaline water to soft, more acidic water. All of these environmental characteristics fundamentally affect the nature of the biota and the sensitivity of both the habitat and the biota to the different consequences of climate change.

At a more detailed level, rivers contain a wide range of biotopes, including riffles and pools, riparian vegetation, exposed sediments, submerged plants, and tree root systems. The availability of these biotopes within a complex mosaic shaped by the river is critical to sustaining characteristic biological communities, particularly in the face of climate change. Biotopes can also vary in their sensitivity to different aspects of climate change.

Rivers change along their length as they flow from source to sea, and these changes lead to broad longitudinal patterns of biological zonation. Within these broad patterns, organisms make a range of migrations, on short and long timescales and of varying distances, to fulfil their life cycle requirements and make best use of available habitat. Connectivity is extremely important to this zonation and associated biological movements - as climate changes, these zonation patterns may migrate upstream and downstream according to shifts in optimal environmental conditions for individual species. The only natural limits to biological movements, apart from occasional natural in-channel obstacles such as waterfalls, are watersheds.

River systems have been modified by man for centuries, through land drainage and flood defence activities, water impoundment, abstraction, diversion, effluent disposal, and energy generation. These modifications impair natural river ecosystem function and impact on the extent and quality of riverine habitats. They also affect the extent to which climate change is likely to damage river ecosystems further, and the scope for adaptation to climate change.

River size has a major influence on the effects of changes in river flow, with smaller rivers being disproportionately affected compared to larger rivers. For such reasons, headwaters might be considered particularly vulnerable to climate change. Groundwater-fed rivers with high base flows might be thought of as more hydrologically resilient to climate change than surface water fed rivers, owing to the scope for groundwater to dampen out short-term reductions in rainfall. This said, the characteristic biota of high base flow rivers will be less well adapted to fluctuations in flow regime, so there may be little difference in terms of broader ecological resilience.

The UK Biodiversity Action Plan (BAP) recognises a number of different river types as being of importance for biodiversity, including chalk rivers, active shingle rivers, and headwaters. However, owing to the continuous nature of habitat change in rivers, and the overlapping nature of different typologies, no attempt has been made in the current UK BAP definitions of priority habitats to separate out different priority river types. A broad priority habitat definition is used for rivers, based around the concept of naturalness. This approach is followed here.

Key ecosystem services associated with rivers and streams

Rivers and streams provide a range of vital ecosystem services, many of which could be affected by climate change. The most important are described below:

Regulating services

Water quality. Rivers and streams are subject to a range of pollutants, from both effluents and diffuse sources. Organic material (particularly from sewage) is broken down by natural microbial processes and released in the form of carbon dioxide and nutrients, which are subsequently taken up by aquatic plants. Particular toxins vary in the extent to which they can be broken down or transformed to harmless substances. Some are merely diluted and dispersed, or tied up in river bed sediments. Over-use of the assimilative capacity of rivers leads to damage to the biological community.

Land drainage and flood defence. Rivers and streams naturally drain catchments by conveying water downstream and ultimately out to sea. They are extensively modified (deepened, widened, straightened) to enhance land drainage and convey peak flows downstream in order to avoid flooding. This results in habitat degradation through simplifying the range of biotopes available, increasing hydraulic hostility, and reducing river length. Some modern forms of flood risk management aim to use natural river processes to promote flooding in suitable areas and thereby reduce flooding of downstream areas, particularly urban areas. In this way, peak flows can be selectively 'vented' by natural river/ floodplain interactions, generating low-energy flooding at suitable points in the river network rather than high-energy flooding further downstream. Such flood-management approaches are compatible with the ecological restoration of river ecosystems.

Carbon sequestration. Rivers and streams are net sinks of carbon in their natural state. However, when carrying elevated levels of nutrients and organic pollution they can become net exporters. Methane export similar to some UK peatlands has been recorded for a chalk stream in southern England (Sanders *et al* 2007).

Cultural Services

Rivers and streams are valuable cultural assets, being a focal point in the landscape and providing widespread opportunities for recreation. Over use of some of these services can result in damage to river ecosystems. The highest levels of cultural services are provided by river ecosystems with high levels of natural ecosystem function and where use of the river is adequately managed.

Provisioning Services

Rivers are used to supply water for a range of human activities, including domestic, industrial, and agricultural use. Over-abstraction from rivers or the groundwater on which they depend can lead to ecological damage. Balancing the needs of the river ecosystem with society's needs for water will become more urgent in the face of climate change.

Potential climate change impacts

Cause	Consequence	Potential impacts
Hotter summers and milder winters	Increased annual average water temperatures	■ Declines in the abundance of cool-water species within current distribution and shifts in the distribution of species, including plants, invertebrates and fish. Evaluations of likely shifts in thermal regimes of upland streams have indicated that regimes in some rivers are likely to move out of the tolerance range of some characteristic species (Durance and Ormerod 2007). Within catchments, the climate space of many species is likely to migrate upstream in instances where cooler water exists (particularly where headwaters are at significant altitude), as long as upstream reaches are within the hydraulic and hydrological tolerances of each species. At a larger scale, where climate space shifts northwards and beyond the watersheds of individual catchments, species without aerial life stages (e.g. fish, molluscs, crustaceans) will find it difficult to migrate as their climate space shifts. Cool-water species such as Atlantic salmon are likely to decline in lowland river systems and populations may become unviable (Milner *et al* 2010). Shifts in species with aerial life stages, such as dragonflies are already being reported further north, sometimes by hundreds of kilometres. Differences in the mobility of species will lead to the changing of community composition and interactions between species. ■ Climate change-induced shifts in phenology will also become apparent, with consequences not only for the species involved but also for food webs, generating knock-on effects for higher trophic levels (e.g. invertebrate phenology affecting fish). In the Peak District, shifts between a two-year and a one-year life cycle of the mayfly *Ephemera danica* have been linked to temperature trends. Differences between trophic levels have been reported, with advances in timing slowest for secondary consumers (Thackeray *et al* 2010). ■ Some aquatic and riparian non-native species may become invasive, and other currently geographically restricted species may spread more easily.
Drier summers	Lower flows and drought	■ Prolonged low flows and associated temporary reductions in habitat extent and quality will lead to increased competition and predation, and unsuitable habitat conditions for cool water, current-loving species (Mainstone 2010). This will affect the passage of migratory fish, including Atlantic salmon. Headwaters are at particular risk of losing perennial habitat in favour of intermittent habitat due to the downstream migration of the perennial head of streams. The opposing effects of warming (forcing cool water species upstream) and reduced summer flows (forcing species downstream) are likely to act in concert to reduce the climate space of many species, and in some cases 'pinch' them out of catchments.
Wetter winters	Higher peak flows	■ This may have both positive and negative effects. Greater hydraulic energy will allow greater natural recovery of river habitat degraded by physical modifications (Mainstone & Holmes 2010). However, it may also lead to a surge of flood defence activity, creating more physical habitat degradation. It may also cause populations of priority species (e.g. freshwater pearl mussel) to be washed out of rivers, and a general downstream shift of species that are less well-adapted to high flows. ■ Increased connectivity in flooding events has the potential to spread invasive non-native species across habitats and water bodies.
Reduced total annual rainfall	Reduced total annual river flow	■ Reduced river flows and a general decline in hydraulic energy will result in a loss of habitat space and a consequent decline in populations of those species favouring faster currents. ■ Increased demand for abstraction could place river ecosystems under even greater stress.
Increased frequency of storms	Increased rainfall intensity and run-off energy	■ Enhanced erosion will lead to increased loads of fine sediment and nutrients, causing siltation and eutrophication.
Carbon reduction programmes	Hydroelectric power schemes	■ If adopted widely and inappropriately, these will reduce the scope for restoring the natural function of river ecosystems and hence reduce resilience to climate change.

Adaptation responses

Measures needed to help rivers and stream adapt to climate change are largely the same as those required to restore their health and integrity generally, through attention to natural ecosystem function. A summary of key measures is provided below – further information on restoring natural river ecosystem function is provided in Mainstone *et al* (2016). There is also the potential to lower water temperatures by providing shade from bankside vegetation and further is available from the Keeping Rivers Cool project (Woodland Trust 2016).

In the catchment

The main priority for adaptation within river catchments will usually be to promote land uses and land management practices that maximise natural rainfall retention within the catchment. This will help to reduce run-off energy and associated diffuse pollution. Allowing more water to be stored within the catchment will also help to reduce the extremes of peak flows and low flows. Other priorities will be slowing the spread of invasive species, and increasing the availability of cooler water by providing riparian shade.

Some of the potential adaptation options for this habitat are outlined below:

- Improve the natural infiltration of catchment soils and percolation to groundwater by restoring soil organic matter levels and avoiding soil compaction and capping.
- Create semi-natural vegetation such as woodland and grassland along critical run-off pathways to slow surface water run-off and aid infiltration of water into the soil.
- Restore natural function of headwater streams, including ephemeral and permanently flowing sections – the health of these streams is vital to the health of the river network and the resilience of catchments to climate change.
- Make sure that crops are appropriate to the erosion sensitivity of the land in order to minimise erosion and siltation of water courses.
- Minimise nutrient (nitrogen and phosphorus) applications to crops to the minimum necessary for healthy growth, based on methods with high uptake efficiencies.
- Use low-nutrient livestock feeds with high efficiencies of nutrient uptake.
- Block drainage where possible and consistent with local agricultural land management objectives.

In the river corridor and floodplain

Maintaining and restoring natural river processes constitute the most ecologically effective climate change adaptation measures for river ecosystems (Kernan *et al* 2012). Natural river processes provide the most characteristic and self-sustaining mosaic of river biotopes (Mainstone *et al* 2016), and provide the best environmental conditions for characteristic species to survive in a changing climate. The restoration of natural river features also has important wider benefits for flood risk management and landscape character.

Some of the potential adaptation options for this habitat are outlined below:

- Manage water demand, impoundment and abstraction to minimise impacts on the natural flow regime of rivers.
- Make use of high rainfall periods to store water (e.g. using small-scale winter storage reservoirs for agricultural irrigation) in order to minimise direct river abstraction during low-flow periods.

- Where consistent with managing flood risk to people and property, free river channels from constraints to natural movement and self-recovery of natural morphology and hydrology. This may involve the removal of weirs, flood banks and hard bank protection.
- Assist natural recovery of rivers by minimising maintenance of the river channel by dredging, weed clearance and the removal of woody debris. Large woody debris, in particular, is a critical part of river ecosystems that is often absent from English rivers.
- Where assisted natural recovery is not possible, actively restore river channels, banks and riparian areas, to create a more natural mosaic of characteristic biotopes. This may involve measures such as bed-raising, bank re-profiling, and riparian tree planting.
- As far as possible, avoid creating new constraints to natural river processes, including weirs, hard bank protection, flood banks and flow modifications (e.g. inter-basin transfers).
- Plan land use and management with river movement in mind. Develop long-term plans for managing the river channel within an 'erodible corridor', using set-back tree planting where necessary to constrain movement beyond this.
- Allocate greater areas of floodplain land to flood naturally, to minimise the build-up of peak flows to downstream urban areas.
- Plan biodiversity management in the floodplain with natural riverine processes and river restoration in mind. Develop a long-term vision for semi-natural habitat mosaics that takes account of river dynamics, and modify site designations and conservation objectives accordingly.
- In treeless river reaches, optimise riparian tree cover to provide patchy light and shade. This provides the best mosaic of biotopes, an ample supply of woody debris and leaf litter, and provides buffering against rising water temperatures, shading the water and lowering temperature on sunny days. The Keeping Rivers Cool project (2016) has published **guidance** on improving the level of shading to help keep rivers cool.
- Where possible, restore natural biological connectivity within the river network and between the river channel and floodplain by removing artificial barriers (in-channel structures and flood banks). Where applicable, the removal of barriers needs to be set against the risk of speeding up the spread of invasive non-native species. This is particularly key in situations where there are native crayfish upstream. Generally, weirs only provide short-term protection against non-native spread, and so this would not normally be considered a long-term constraint to weir removal. Natural in-river barriers (typically waterfalls) play a role in the development of certain types of biological community (e.g. fishless headwaters) and should not be removed.
- Where removal of weirs is not possible, minimise their impact on channel morphology/hydraulics and the free movement of species. This may involve reducing the height of the weir and/or providing bypass routes for as many species as possible, including weak swimmers (such as shad *Alosa spp*) where appropriate.
- Where needed, species under threat from shifts in climate space may be targeted for assisted migration, working in line with guidelines for species translocations.
- Manage pollutant loads from effluents to minimise impacts on natural nutrient status and to minimise concentrations of toxins.
- Plan the development of hydroelectric power schemes to avoid constraining the restoration of natural river processes, since the latter is the key climate change adaptation measure for river ecosystems. Development should be focused on existing impoundments that cannot be removed, and on in-line turbines that do not remove water from the river channel.

'Natural' timber posts to slow down water as part of flood management in The Cheviots. © Sarah Taylor

Relevant Countryside Stewardship options

Many of the actions outlined above can be supported by Countryside Stewardship. The most relevant Countryside Stewardship options relating to catchments concern resource protection. Their main aim is to reduce soil erosion and nutrient inputs, but they often work by reducing surface run-off, thereby improving catchment and soil infiltration rates. Further incentives for agricultural erosion and nutrient control are provided by the **Catchment Sensitive Farming** scheme. Options of most relevance to the riparian corridor include the Making Space for Water option (SW12), which provides support for removing constraints to lateral movement of the river channel. Restoring this movement is critical to re-naturalising morphological processes, which is needed to restore the full river habitat mosaic as well as to maximize natural flood management benefits. The Riparian Management option (SW11) supports measures to restore riparian habitat strips, although a more bespoke set of Stewardship options may be needed to restore the riparian zone of river SSSIs and priority river habitat. A range of options for restoring semi-natural habitats in the floodplain can be used to support adaptation measures involving restored lateral river connectivity.

Other actions may be supported by water-related funding streams, particularly Water Framework Directive implementation, Flood Risk Management budgets, and the water industry's Asset Management Plan (AMP) process.

Further information and advice

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Relevant case study examples

Restoring Designated Rivers. The national programme of physical restoration of the river SSSI network. A collaboration between Natural England and the Environment Agency with a wide range of contributors.

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Watendlath Tarn, Cumbria
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11. Standing open water

Climate Change Sensitivity: **High**

Introduction

Climate change is predicted to bring about a range of changes to environmental conditions in lakes and ponds, including shifts in temperature and hydrological regimes. This will bring about changes in the sediment and nutrients delivered to and retained by lakes and ponds. In turn, biological processes will respond to these changes. Some of these changes are already happening and are likely to intensify. The patterns and behaviours of the wildlife associated with our lakes and ponds will change as a result. A range of measures are required to help our lakes and ponds adapt to these changes.

Warmer temperatures will threaten the persistence of some species on the southern edge of their range such as vendace *Coregonus albula*, shelly *Coregonus lavaretus* and arctic charr *Salvelinus alpinus*, and allow other species to spread northwards to new locations within the UK where they can disperse between water bodies, for example dragonflies and damselflies.

Increased temperatures and longer growing seasons may intensify the symptoms of eutrophication, with a greater frequency and duration of algal blooms where nutrient loads are sufficient to support them. This is likely to reduce macrophyte abundance, which will affect the higher trophic levels. There is the potential for mismatches between phytoplankton and zooplankton due to changes in phenology, which may result in zooplankton grazers being unable to control phytoplankton levels. Increased phytoplankton levels will create increased demand for oxygen as the phytoplankton decomposes. This will reduce the oxygen concentration at the sediment-water interface, potentially leading to an increased phosphorus release from the sediment. It has been suggested that climate change may act as a forward switch to a turbid algal dominated state within shallow standing waters.

Even without the increased productivity, higher water temperatures will lead to a reduction in dissolved oxygen concentration, making phosphorus release from the sediment more likely and consequently increasing the nutrient load to the lake from internal sources. Species reliant on well oxygenated water will potentially have their habitat reduced by increased temperatures reducing oxygen concentrations.

Wetter winters and an increase in the frequency of storm events could increase the run-off of silt and nutrients to water bodies, resulting in the increased potential for eutrophication and the potential physical impacts of sediment covering substrates and/or macrophytes. However, wetter conditions can also reduce the water residence time within lakes and increase flushing, which may reduce the concentration of nutrients within a lake, if the water entering the lake has a lower nutrient concentration than the lake water.

Drier summers can have the opposite effect, reducing run-off and thereby reducing nutrient and silt delivery during the summer. Drier summers can also increase retention times and therefore reduce the flushing of nutrients from lakes. Some sites may completely dry out in summer, resulting in the temporary loss of freshwater habitat. However, temporary water bodies still support a range of distinctive flora and fauna.

Drier summers, increased frequency of storms and wetter winters will all result in greater fluctuations in water levels. This will potentially create a wider littoral zone, subject to greater variation in water availability and consequent wave impacts. Whether species can survive the increased stress of these greater water level fluctuations will depend on the extent, speed, timing and frequency of these fluctuations. Fluctuating water levels may also result in increased erosion of both the lake sediments and the shoreline. The magnitude of wave action will depend on lake size, orientation and the extent to which the site is exposed to the wind. As water levels across the wider environment fluctuate, sites previously unconnected may become connected via flood events, and sites which were previously connected may become unconnected during summer droughts. The loss of connectivity will be of particular importance for sites suffering permanent or temporary freshwater habitat loss or change as species will need to migrate to other standing freshwater sites.

Saline intrusion at the coast resulting from rising sea levels will result in affected freshwaters becoming increasingly brackish. This change will result in some water bodies becoming uninhabitable for many of the species they currently support, but they may become more suitable for others. Saline intrusion may also trigger a switch to an algal dominated state.

Standing water systems are under threat from a wide range of non-native species, some of which may be better adapted and spread more quickly in a changing climate. Many of the species whose spread may be facilitated by higher temperatures originate from the Ponto-Caspian region of eastern Europe. These species have already spread into western mainland Europe via a number of routes, most recently the Rhine-Danube canal, and some such as the killer shrimp *Dikerogammarus villosus* have already made their way to the UK.

Climate change also has the potential to affect the pH of standing waters, but this will depend on the hydrological and geological conditions of the site.

Habitat Description

This section provides a short summary of how lake and pond habitats are shaped and how they function. A fuller description is provided in Mainstone *et al* (2016).

Five BAP categories can be considered within the standing waters habitat type. These are: aquifer fed naturally fluctuating water bodies, ponds, oligotrophic and dystrophic lakes, mesotrophic lakes, and eutrophic lakes. Aquifer fed naturally fluctuating water bodies occur over chalk in the Norfolk Breckland and consist of natural water bodies which have an intrinsic regime of extreme fluctuation in water level, with periods of complete or almost complete drying out as part of the natural cycle. They have no inflow or outflow streams at the surface, except at times of very high water level, when temporary out-flows may develop. Instead, they are directly connected to the underlying groundwater system and periodically empty and are recharged via swallow holes or smaller openings in their beds.

Ponds, for the purpose of UK BAP priority habitat classification, are defined as permanent and seasonal standing water bodies up to 2 ha in area. Ponds are widespread throughout the UK, but high-quality examples are now highly localised, especially in the lowlands. In certain areas, high quality ponds form particularly significant elements of the landscape, for example, the marl pits in Cheshire and Norfolk, the New Forest ponds, and the pingos of East Anglia.

The remaining three lake categories contain water bodies greater than 2 ha in size and represent a continuous gradient of productivity. Oligotrophic lakes are the least productive. Their catchments usually occur on hard, acid rocks, most often in the uplands. Dystrophic lakes have peat-stained water and are most often oligotrophic and are therefore included in the oligotrophic lake BAP category, but they can have different trophic statuses. Oligotrophic and dystrophic lakes occur throughout the UK, but mostly in upland parts of the north and west. They encompass a wide range of sizes and depths, and include the largest and deepest water bodies in the UK.

Eutrophic lakes are the most productive and have the highest nutrient concentrations, although naturally these nutrient concentrations would not have been excessive, enabling a range of submerged plants to grow. Eutrophic lakes are most typical of hard water areas in the lowlands of southern and eastern Britain, but they also occur in the north and west, especially near the coast. Mesotrophic lakes lie in the middle of the trophic range and as a consequence have a high botanical diversity. Mesotrophic lakes are relatively infrequent in the UK and are largely confined to the margins of upland areas in the north and west.

The total area of still inland water is estimated at 675 km^2 in England.

Potential climate change impacts

Cause	Consequence	Potential impacts
Sea Level Rise	Saline intrusion	■ Loss of freshwater flora and fauna. ■ Forward switch to a turbid algal dominated state. ■ Increased frequency of flips between saline, brackish and freshwater states.
Increased frequency of storms	Higher intensity rainfall, leading to increased run-off	■ Increased run-off of sediment and nutrients, leading to eutrophication and sedimentation. Sedimentation can reduce recruitment in some fish species such as vendace *Coregonus albula*, which require clean gravels for spawning. Eutrophication has the potential to impact upon the entire food web. ■ Fluctuation in water levels causing erosion by waves over a wider area.
Increased annual average temperatures	Longer growing season	■ Increased likelihood of eutrophic symptoms where nutrient loads are high, with earlier and longer lasting phytoplankton blooms. ■ Possible increased abundance of Cyanobacteria ('blue-green algae') within the phytoplankton community, although this has not always been supported by experimental work, especially in shallow water systems containing macrophytes. ■ Raised phytoplankton productivity causes a reduction in light penetration, competition for carbon dioxide, and a decrease in oxygen concentration as phytoplankton decomposes. This can cause a loss of macrophytes and a loss of those fish which are reliant on high oxygen levels. Benthic organisms may also decline due to inhospitable conditions in the benthos, and eventually zooplankton will decline as there is no refuge from zooplanktivorous fish as the macrophytes have been lost. This will result in an algal dominated turbid lake with reduced biodiversity. ■ Phenology within the plankton community is likely to change with the potential for mismatches between different components of the plankton community, leading to changes in the relative abundance of species. ■ Possible replacement of submerged macrophyte species by evergreen and/or floating macrophyte species. Successful evergreen species may be non-native, such as New Zealand pygmy weed *Crassula helmsii*. ■ Non-native species, especially those which currently have a more southern and/or eastern distribution, are increasingly likely to colonise and expand their range. ■ The reproductive success of introduced and problematic fish species such as the common carp *Cyprinus carpio* may increase as temperatures increase. Some aquatic and riparian non-native plant species may become invasive due to improved winter survival rates. ■ Loss of habitat for cold water species and northward spread of some southern species. Potential for changes in pH due to increased weathering.
	Lower dissolved Oxygen levels	■ Increased likelihood of deoxygenated conditions at the sediment-water interface, leading to the release of phosphorous from the sediment into the water and a risk of eutrophication. As a result, some invertebrate and fish species may find it difficult to survive low oxygen levels.

Cause	Consequence	Potential impacts
Drier summers	Drought	■ Greater water level fluctuations leading to increased exposure of the littoral zone (causing stress for some aquatic plant species) and leading to increased erosion lower down the littoral zone. Encroachment of marginal emergent vegetation into the water body. ■ Drying of the marginal vegetation at the outer edge. ■ Longer and more frequent drying out of shallow/small water bodies. While drying out is detrimental to some species, other species such as the tadpole shrimp *Triops cancriformis* thrives in such conditions. ■ Loss of physical connection with other freshwater and wetland habitats. ■ Potential for changes in pH due to changes in hydrological conditions.
	Decreased summer flushing/longer retention times in summer	■ Increased nutrient concentrations within water bodies, potentially making it harder to recover from eutrophication.
Wetter winters	Flooding	■ Flooding higher up the shoreline, resulting in increased erosion of the shoreline as water levels rise and displace the usual drawdown zone. ■ Increased run-off, sediment and nutrient delivery, leading to sedimentation and eutrophication. ■ Increased winter flushing and shorter retention times in winter, potentially reducing nutrient concentrations lakes in winter if the water entering the lake has a lower nutrient concentration than the lake water.

Adaptation responses

Action to promote adaptation within standing waters needs to take place at a range of scales both within the water bodies themselves and within their catchments. Reducing non-climatic sources of harm can help to increase resilience. This should include reducing nutrient and sediment loads, reducing water management pressures (e.g. abstraction, water diversion/transfer) and controlling non-native species.

Establishing ecological networks and ensuring hydrological connectivity is maintained between naturally connected sites is important to allow species to migrate between sites in response to climate change. However, many standing waters are naturally isolated and artificially connecting such sites may have detrimental effects. These include the easier movement of non-native species and the movement of pollutants into previously unpolluted water bodies. The standing water ecological network can be enhanced by the creation of additional ponds, as they act as stepping stones between standing water sites. In contrast, it is much harder to create new lakes, although there may be some opportunities where minerals have been extracted.

Habitat heterogeneity is important to allow species to respond successfully to some of the difficulties associated with climate change. Examples of heterogeneity in standing waters include ponds at varying stages of succession and with varying depths and permanence of water, and lake shorelines with natural process of succession and patterns of species zonation.

While all standing water sites will be subject to the influences of climate change, those away from the coast may provide refugia for species which would otherwise be subject to saline intrusion. Coastal Habitat Management Plans (CHaMPs) will help identify where saline intrusion at freshwater sites is inevitable. In these situations, additional habitat creation inland should be considered. This is most practical for coastal ponds. If species of conservation concern with poor dispersal ability inhabit the at-risk sites, assisted migration will need to be considered. However, this needs to be incorporated into long term planning before saline intrusion occurs.

Some of the potential adaptation options for this habitat are outlined below:

In the catchment

- Improve natural infiltration of catchment soils and percolation to groundwater, by restoring soil organic matter levels and avoiding soil compaction and capping.
- Create semi-natural vegetation such as woodland and grassland along critical run-off pathways to slow surface water run-off and aid infiltration of water into the soil.
- Make sure that any crops grown are appropriate to the erosion sensitivity of the land in order to minimise erosion and siltation of water courses.
- Restrict nutrient (nitrogen and phosphorus) applications to crops to the minimum necessary for healthy growth, based on methods with high uptake efficiencies.
- Use low-nutrient livestock feeds with high efficiencies of nutrient uptake.
- Use Coastal Habitat Management Plans (CHaMPs) to assess which sites are at risk from saline intrusion and whether habitat creation or assisted migration is required.
- Replace lost habitat and provide stepping stones to allow species to move through the environment where appropriate via the maintenance of the existing ponds and the creation of new ponds. The Wetland Vision (Hume, 2008) includes the aspiration to double the number of ponds in the next fifty years, and includes maps identifying areas suitable for pond creation.
- Lakes are a relatively fixed resource in England; their distribution being fixed by past glacial activity and other topographical features, but there may be some opportunity to create new lakes where minerals have been extracted.

The standing water body

- Manage pollutant loads from effluents to minimise impacts on the natural nutrient status and to minimise concentrations of toxins.
- Maintain or restore lake marginal habitat and emergent structure to provide areas protected from wave action.
- Maintain or restore the natural hydrological regime including action that reduces drainage of surrounding wetlands and allows natural water level fluctuations and flushing rates.
- Optimise shoreline tree cover to provide some areas of shade. While shading reduces plant growth in standing waters, an ample supply of woody debris and leaf litter is beneficial to some species, and buffers against rising water temperatures, and therefore a limited amount of shade is beneficial.
- Manage access and leisure activities to minimise impacts and increase resilience.
- Promote good biosecurity to slow the spread of invasive non-native species and minimise their chances of colonising the water body and control damaging species already present.

Relevant Countryside Stewardship options

Many of the actions outlined above can be supported by Countryside Stewardship. The most relevant Countryside Stewardship options relating to catchments are the soil and water options. Their main aim is to reduce soil erosion and nutrient inputs, but they often work by reducing surface run-off, thereby improving infiltration rates. Further incentives for agricultural erosion and nutrient control are provided by the **Catchment Sensitive Farming** scheme. More direct water body management can be supported by the capital item WN7 for restoring large water bodies, the pond management options WT4 & 5 and capital items WN5 & 6 which can be used for pond restoration or to create new ponds. These options can also be used for controlling damaging species. In addition, fen creation and management options (WT8 and 9) may also be used to help establish a natural hydrosere[4] and reduce drainage of transitional land. A range of options for restoring semi-natural habitats in the catchment can be used to support adaptation measures involving reducing impacts from the catchment.

Others actions may be supported by water-related funding streams, particularly Water Framework Directive implementation, Flood Risk Management budgets, and the water industry's Asset Management Plan (AMP) process.

Relevant case study examples

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4 A hydrosere is a plant succession which occurs in an area of fresh water. In time, an area of open freshwater will naturally dry out, ultimately becoming woodland

Aqualate Mere NNR, Staffordshire. ©Natural England/Mel Brown

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Lowland fen, Test Valley, Hampshire.
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12. Lowland fens

Climate Change Sensitivity: **High**

Introduction

Lowland fen can be highly sensitive to changes in the quality and quantity of water supply and its seasonal availability, all of which are likely to alter significantly under climate change. The direct impacts of changes to precipitation and temperature pose a severe threat to lowland fen habitat. Resilience to these impacts is currently compromised on many fens by existing pressures such as diffuse water pollution, atmospheric nitrogen deposition and the effects of drainage. Human responses to climate change, such as increased pressure on scarce water resources, may compound such pressures.

Sea level rise and associated saline intrusion will pose an increasing threat to fen close to the coast.

Habitat Description

Fens are wetlands that occur on peat and mineral soils and which can receive water from various sources (groundwater, surface run-off and river flooding, as well as rainfall), unlike bogs, which receive water at their surface only from precipitation. Fens are complex and dynamic systems. They frequently form complex mosaics with a number of associated habitat types, including wet woodland (fen carr), bogs, lowland heathland and lowland meadow.

The character of a fen is largely determined by the landscape setting, and the quantity, quality (in terms of macro-nutrients N, P & K) and chemistry (e.g. pH) of the water that supplies it. These various factors interact to create an extremely wide range of conditions in which fen vegetation occurs, and result in the development of a very wide range of vegetation types. In order to understand the likely impacts of any external pressure on a fen, including climate change, it is essential that the eco-hydrological function of the individual wetland (i.e. where the water comes from, how it moves through the site, the chemistry and nutrient status of the water, the nature of the substrate, and vegetation present) is understood. Management is also important, and understanding the influence of historical management as well as current practice is necessary.

Fens occur across the pH range, along a nutrient gradient from highly eutrophic through to oligotrophic, and along a wetness gradient from seasonally waterlogged through to permanent standing water. The vegetation changes across these gradients, with many transitional forms. At the acidic low-nutrient end of the spectrum, fens can resemble bogs, with abundant Sphagnum mosses, cotton grasses, cranberry and ericaceous shrubs. As base content increases, species such as devil's-bit scabious *Succisa pratensis* and marsh cinquefoil *Potentilla palustris* increase.

The change in fen bryophyte composition is a strong indicator of changing environmental conditions, and as base-richness increases a range of very distinctive non-Sphagnoid mosses and liverworts develops, known as the 'brown-moss' layer. This has a very important function in maintaining moisture levels, providing both a rooting substrate for vascular plants, as well as a home for numerous rare and declining invertebrates such as Geyer's whorl snail *Vertigo geyeri*, soldier flies and craneflies. Alongside these bryophytes, low-growing sedges and sedge allies such as dioecious sedge *Carex dioica* and black bog rush *Schoenus nigricans*, and more photogenic species such as butterworts *Pinguicula*, bird's-eye primrose *Primula farinosa* and marsh valerian *Valeriana dioica* are found.

Great Fen. © Natural England/ Sarah Taylor

In areas where base-rich water occurs in more nutrient rich conditions, tall species-rich fen may develop, e.g. the Broads fens. These fens are typified by the presence of common reed *Phragmites australis*, large sedges, yellow loosestrife *Lysimachia vulgaris*, hemp agrimony *Eupatorium cannabinum*, and some scarcer species such as greater water parsnip *Sium latifoilum*, cowbane *Cicuta virosa*, and saw sedge *Cladium mariscus*. They are often a later successional stage of 'swamp', an early successional fen type characterised by more-or–less permanent standing water and often dominated by sedges, reed or reed mace *Typha spp*.

Fen meadow vegetation develops in various situations, sometimes as a result of regular cutting or grazing of tall-herb fen, but also around the drier margins of wetter fen types, and in drained ex-fen sites. It tends to be associated with slightly lower summer water tables than 'true' fen (although this is not always the case) and consequently has a greater representation of grassland plants amongst the wetland species.

Lowland fen is found across England, from sea level up into the hills. Certain types of fen are restricted to parts of the country where the necessary environmental conditions occur; for example, alkaline fens are limited to areas with low-nutrient calcium-rich groundwater, and basin fens with floating acidic rafts tend to occur in hummocky, often post-glacial, landscapes. Although the estimated area of lowland fen in England is 25,785 ha[5], certain types of fen are now extremely rare, for example, there is now less than 50 ha of black bog-rush – blunt-flowered rush fen (one of the most species-rich fen types) remaining in England (Tratt *et al*, 2013). In general, fens of low nutrient and very wet conditions are now much less common than those of high nutrient situations in the lowlands, and most of those that remain are threatened with nutrient enrichment. It is these low nutrient fens that support many of the most valued and threatened species.

5 JNCC Extent & Distribution of UK Lowland Wetland Habitats.

Potential climate change impacts

Cause	Consequence	Potential impacts
Increased mean temperatures	Longer growing season	■ Increased plant growth will require altered management requirements, especially cutting regimes and stocking density.
Hotter summers	Higher nitrogen concentrations resulting from reduced water volume and increased mineralisation. Higher evapotranspiration	■ Increased nutrient loading may lead to eutrophication of ditch networks and an increased dominance of invasive generalist species. ■ Higher evapotranspiration is likely to compound the effect of drought – see below.
Altered seasonal rainfall patterns	Increased seasonal variation in water table levels	■ Loss of wetland specialists with narrow hydrological requirements.
Drier summers	Increased soil moisture deficit Drought Increased demand for water for agriculture and domestic use, potentially leading to increased abstraction and reduced water availability Low flows, leading to reduced dilution of pollution and nutrient enrichment	■ Drying out of fens in summer, leading to a loss of individual species and changes in community composition. ■ Drying and oxidation of peat, followed by a release of nutrients, leading to further changes in community composition. ■ Colonisation and competition by species more suited to lower water tables and drier conditions. ■ Lower water tables leading to ground conditions becoming suitable for intensification of grazing or conversion to arable cropping, leading to a direct loss of habitat? ■ Changed community composition, with increasing dominance of invasive, generalist species.
Wetter Winters	Increased risk of polluted run-off	■ Increased nutrient inputs from in-washed sediment, leading to the loss of nutrient-poor vegetation types and associated species.
Increase frequency of extreme rainfall events	Increased frequency of flooding Unpredictable inundation of floodplain fen	■ A shift in species composition to favour those species able to cope with long-term inundation. ■ Potentially increased nutrient input, leading to benefits for those species able to utilise enhanced levels, and the potential loss of low-nutrient fens. ■ Increasing difficulty of management, leading to potential abandonment. ■ Increased peat slippage and erosion in sloping valley head mires.
Sea Level Rise	Saline Intrusion Increased frequency of saline inundation	■ Changes in community structure of sites near the coast, with a shift from freshwater to brackish communities. ■ A shift towards inter-tidal habitats.

Adaptation responses

Maintaining and enhancing the quality and quantity of water is likely to be the main objective of adaptation. There are various existing drivers that require action to improve availability of water and water quality, including the Water Framework Directive (WFD) and the Environment Agency's Restoring Sustainable Abstraction programme. It is critical that risks to fens from climate change and other pressures are considered in the context of these, and that actions to improve resilience as well as the current status are identified and included in relevant programmes and plans, particularly the WFD River Basin Management Plans, which are updated at five-year intervals, and the Water Companies' Asset Management Programme (AMP) associated with the five yearly price review.

The requirement for a flexible management regime of grazing and/or cutting that is able to adjust to seasonal variation in rainfall is also important. This will remain a challenge due to the low financial returns that management of these habitats provide.

Removing or reducing pressures on wetlands, including groundwater abstraction, drainage and nutrient enrichment will continue to be critical. As well as dealing with licensed activities such as abstraction, this may involve the designation of larger areas to protect land around wetlands, and improved management of soil and water within catchments.

Restoring natural hydrological processes on and around wetland sites is likely to improve the resilience of features. This may not always be feasible or appropriate, for example on sites that have been created and sustained wholly by human intervention, but in many circumstances it should be seriously considered. In the first instance, this will require an understanding of how the site functions hydrologically, and any existing pressures and modifications to the wetland. For example, many fen sites retain artificial drainage networks which have been perpetuated for no reason other than 'it's always been there'. Consideration should be given to removing this drainage unless it is critical to a very high value feature or infrastructure/property.

Climate change is likely to alter the successional processes of wetland communities and active management is likely to be required to maintain the various stages in their current form, if that is the desired option.

National strategic documents such as the England Wetland Vision can be used to help identify priority areas for restoration and creation of fenland habitat, as part of sustainable drainage and flood defence systems.

Lowland fen communities will change under climate change and the extent to which change is accepted and managed will need careful consideration in each location, taking account of the particular circumstances.

Some of the potential adaptation options for this habitat are outlined below.

- Determine and characterise all aspects of the water regime, reference ecological and hydrological state, existing state, pressures and threats, and the feasibility of restoration options, to ensure that any interventions are carried out with full knowledge of the site's value and function.

- Ensure appropriate management through cutting or grazing combined with scrub management where required, to ensure that habitats do not develop into scrub or woodland.

- Ensure management is sufficiently flexible to provide appropriate management under a range of growing conditions. For example, ensure sufficient land is available to provide alternative grazing in years when fen is flooded.
- As far as possible, restore the natural function of floodplains. For example, consider restoring the connectivity of the floodplain, and filling in drained springs.
- Evaluate the existing drainage within and around fen sites as part of an eco-hydrological characterisation and identify which drains should be filled in or blocked and those which may be necessary to maintain water levels within the site. This will depend on landscape context and historical management.
- Remove sources of nutrient enrichment by increasing the area of extensively managed land around the wetland, and implementing good practice throughout site catchment.
- Increase the heterogeneity of habitats on larger sites by varying management regimes to produce a mosaic of habitat types, including open, unshaded areas free from scrub encroachment or trees, through to more wooded areas.
- Monitor and address potentially harmful invasive native and non-native species. This might include the use of surveillance to detect the arrival of species at an early stage (while they can still be eradicated) and the identification of potential sources of invasive species in the surrounding area.
- Identify and protect sites and areas within sites where the water quality and quantity is likely to be assured in the future. Long-term strategic planning will be required to determine the rate of loss of sites adjacent to the coast, and to identify appropriate locations and mechanisms for compensating for that loss through habitat creation and restoration inland. Ensure though that saltwater/freshwater transitions are allowed to develop naturally, as these are currently very rare and lacking from many coastal areas.
- Locations for the restoration or creation of fen habitats should be identified at the planning stage of flood management schemes within river floodplains.

Relevant Countryside Stewardship options

WT8 Management of fen

This option is targeted at maintaining or restoring areas of fen that are typically dominated by rushes, sedges and wetland grasses. Through the continuation or reintroduction of appropriate management, the option is designed to retain and/or increase botanical diversity.

WT9 Creation of fen

This option is targeted at areas of potential fen, which may have been recently drained, cultivated and/or which lie adjacent to existing areas of fen. The management objectives will vary depending on the location, type of vegetation present and on the past management of the site. Although the development of increasing botanical diversity will often be a major objective, many of these sites will have the potential to also support birds and invertebrates.

WT11 Wetland cutting

The aim of this supplement is to support a cutting regime where this is the most appropriate form of management for the habitat. In addition, this option may maintain local techniques and traditions otherwise at threat of loss.

WT12 Wetland grazing

The aim of this supplement is to support a grazing regime where this is the most appropriate form of management for the habitat.

Further information and advice

Scottish Natural Heritage (2011) **The Fen Management Handbook**
This handbook is produced by Scottish Natural Heritage aims to improve managers' understanding of fens and how they function, to explain why fens need management, and to provide best practice guidance.

Centre for Ecology & Hydrology **Wetland toolkit for Climate Change**
The Wetland Toolkit for Climate Change guides the user in the application of tools developed to assess how climate change in the 2050s (2041-2070) might impact on wetland ecohydrology in England and Wales. The guidance and the tools are designed to be used by anyone concerned with the impacts of climate change on wetlands. It is anticipated that the main users will be site managers concerned with the status of their wetlands.

Environment Agency **A Wetland Framework for Impact Assessment at Statutory Sites in England and Wales**.
Wetland scientists at the University of Sheffield have developed a way of classifying wetlands based on an understanding of where their water supply comes from and the environmental and landscape conditions in which the wetland has developed.

Understanding how a wetland 'works' means that important habitats can be protected, as we can assess where, when and how changes in certain aspects such as groundwater supply and water quality may affect the wetland.

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Relevant case studies

The Great Fen project
The Great Fen is a 50-year project to create a 3,700ha landscape of mixed wetland habitats around Woodwalton Fen and Holme Fen National Nature Reserves in Cambridgeshire. Adaptation to climate change is an integral part of the project, both by providing flood water storage to reduce the impact of climate change on local communities, and by helping wildlife move and adapt to changing climatic conditions.

New Forest wetland restoration
The New Forest supports one of the biggest and richest valley mire systems in western Europe, as well as many other very important habitats. Many of the wetlands and

associated streams have been damaged by historical drainage and river deepening. This programme is restoring natural hydrological function to many parts of the forest, and in doing so is restoring fens, pools, streams and wet heaths, and leaving them in a more resilient state, with benefits downstream as well.

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Boardwalks Local Nature Reserve, Peterborough. © Natural England/Peter Wakely

Yare Broads and Marshes SSSI
© Natural England/Paul Glendell

13. Reedbeds

Climate Change Sensitivity: **Medium**

Introduction

Reedbeds are highly sensitive to changes in the quantity of water supply, requiring an above surface or near surface water table throughout the year. Reedbeds are perhaps less sensitive to changes in water quality than other fens, being a relatively nutrient rich habitat, although the richest reedbed ecosystems are associated with water of high quality.

The combination of the direct impact of changes to precipitation and temperature and the indirect impacts of increasing demand for water leading to increased abstraction will pose a severe threat to reedbeds and other lowland fen habitats.

Sea level rise and potential increased storminess will lead to increased saline intrusion on sites adjacent to the coast.

Habitat Description

Reedbeds are early successional wetlands, dominated by stands of the common reed *Phragmites australis*, where the water table is at or above ground level for most of the year. They tend to incorporate areas of open water and ditches, and small areas of more diverse fen, wet grassland and carr woodland may be associated with them.

Reedbeds are very important habitats for birds in the UK. They support a distinctive breeding bird assemblage, including six bird species which are largely, or totally, restricted to this habitat during the breeding season; the bittern *Botaurus stellaris*, marsh harrier, *Circus aeruginosus*, common crane *Grus grus*, Cetti`s warbler *Cettia cetti*, Savi`s warbler *Locustella luscinioides* and bearded tit *Panurus biarmicus*. They also provide roosting and feeding sites for migratory species, including the globally threatened aquatic warbler *Acrocephalus paludicola*, and are used as roost sites for several raptor species in winter. Five GB Red Data Book invertebrates are also closely associated with reedbeds, including the reed leopard moth *Phragmataecia castanaea* and a rove beetle *Lathrobium rufipenne*.

Reedbeds are found across England, from sea level to higher altitudes, and often fringe open water and watercourses. The largest areas are in coastal areas of East Anglia, with important reedbeds also found in the Somerset Levels, the Humber Estuary and north west England.

There are about 5,000 ha of reedbeds in the UK, but of the 900 or so sites contributing to this total, only about 50 are greater than 20 ha, and these make a large contribution to the total area.

Potential climate change impacts

Cause	Consequence	Potential impacts
Warmer winters	Fewer frost days	■ An increase in the population of pests such as wainscot moths could affect the commercial viability of harvesting reed and compromise its management.
Hotter summers	Higher water temperature in ditch networks	■ Higher water temperatures could lead to changes in the abundance and distribution of some species.
Drier summers	Drought Increased abstraction for agriculture and domestic use leading to reduced water availability Increased threat of wildfire	■ Drying out of reed beds in the summer could lead to the loss of aquatic species and changes in community composition. Reedbeds could be colonised by species more suited to lower water tables and drier conditions, such as willow. ■ Specialist invertebrate and bird species could decline or be lost. ■ Drying out could lead to sites becoming less favourable to species requiring very wet reedbeds, such as bittern.
Wetter Winters	Increased incidence of winter flooding	■ Continual water-logging will make it difficult to manage sites by cutting or burning.
Increase frequency of extreme rainfall events	Increased soil run-off and nutrient enrichment from catchment	■ An increase in nutrient loading could have impacts on aquatic vegetation, invertebrates and fish.
Sea Level Rise	Saline Intrusion Increased frequency of saline inundation	■ Saline intrusion could lead to changes in community structure of sites near the coast, with a shift from freshwater to brackish communities, and ultimately a shift towards salt marsh. ■ Saline inundation kills freshwater fish, so reducing the food supply for bitterns and other fish feeders in the short term.

Adaptation responses

Extensive reedbeds, as an early successional natural habitat, have been lost from most natural wetland ecosystems. Consequently, the largest and most biodiverse reedbeds are now largely found in modified, intensively managed sites. In these situations, water management and vegetation management are necessary to maintain conditions for the persistence of reed-dominated vegetation, which in a natural system, as peat accumulated, would generally succeed to different wetland habitats, or would be maintained by dynamic riverine/coastal processes. The maintenance of a high water table is likely to be the main adaptation challenge. Management of the reed itself will need to be flexible in terms of timing and extent to respond to annual variations in ground conditions.

Reedbed has suffered widespread loss due to drainage, agricultural improvement and abandonment over the last century, and the remaining areas are often small and fragmented. Measures to increase their size, restore more natural hydrological regimes, and connect them to other wetlands will play an important role in increasing the resilience of remaining sites.

In addition, significant habitat creation and restoration will be required to replace sites lost to saline intrusion at the coast. Opportunities will arise for the restoration and creation of reedbed as part of sustainable drainage systems and flood defence schemes, although the value of these for the core 'reedbed' species may be limited, depending on size and quality.

Some of the potential adaptation options for this habitat are outlined below:

- Seek opportunities to allow development of reedbed in its natural position through the restoration of large naturally-functioning wetland complexes.
- Ensure appropriate management through cutting or grazing, combined with scrub management where required, to ensure that habitats do not develop into scrub or woodland.
- Ensure management is sufficiently flexible to provide appropriate management under a range of growing and ground conditions.
- Manage ditch networks to increase their capacity to store high flows and flood water, and to maintain water table height in periods of low flows.
- Increase the heterogeneity of habitats on larger sites through varying management regimes to produce a range of age classes and areas of dead thatch.
- Make best use of available water (and acquire new sources of suitable water where practical) to enable water tables to be maintained during the spring and summer.
- Identify and protect areas within sites where the security of water supply will be assured in the future.
- Where long-term water availability is unlikely to be maintained, revise the objectives for the site and determine the most effective management options to facilitate change. For example, manage the site through cutting to facilitate the transition into a lowland fen-type habitat, or allow and encourage scrub development and/or undertake planting to move the site towards wet woodland, depending on local priorities and conditions.
- Seek opportunities to replace or create reedbed when flood management schemes within river floodplains are being designed. Significant reedbed creation will be required to replace sites lost near the coast.

Bearded tit on reed. © Natural England/Allan Drewitt

Relevant Countryside Stewardship options

WT6 Maintenance of reedbeds

This option is targeted at the maintenance and restoration of areas of wetland that are dominated by reeds. Many sites have been degraded through water extraction, drainage, lack of management and pollution. By re-introducing appropriate management techniques and ceasing damaging practices this option restores degraded reedbeds and associated fauna.

WT7 Creation of reedbeds

The aim of this option is to create areas of new reedbed on land of existing low conservation interest and to support wild bird and various invertebrate species that are associated with reedbed habitat.

WT11 Wetland cutting

The aim of this supplement is to support a cutting regime where this is the most appropriate form of management for the habitat. In addition this option may maintain local techniques and traditions otherwise at threat of loss.

Further information and advice

Centre for Ecology & Hydrology **Wetland toolkit for Climate Change**
The Wetland Toolkit for Climate Change guides the user in the application of tools developed to assess how climate change in the 2050s (2041-2070) might impact on wetland ecohydrology in England and Wales. The guidance and the tools are designed to be used by anyone concerned with the impacts of climate change on wetlands. It is anticipated that the main users will be site managers concerned with the status of their wetlands.

Scottish Natural Heritage **The Fen Management Handbook**
This handbook produced by Scottish Natural Heritage aims to improve managers understanding of fens and how they function, to explain why fens need management and to provide best practice guidance.

Environment Agency (2004) **Ecohydrological Guidelines for lowland wetland plant communities 2004,** and Fens and Mires update 2010.

Mainstone, C., Hall, R. & Diack, I. (2016). **A narrative for conserving freshwater and wetland habitats in England**. Natural England Research Reports No 064.

White, G., Purps, J. & Alsbury, S. (2006). The bittern in Europe: a guide to species and habitat management. The RSPB: Sandy.

Hawke, C. J. & Jose, P. V. (1996). Reedbed Management for Commercial and Wildlife Interests. The RSPB: Sandy.

RSPB (2011) **Bringing Reedbeds to Life Wildlife Survey Programme Executive Summary**

JNCC (2008) UK BAP habitat description **Reedbed**.

Reedbed at Tarn Moss NNR, Cumbria. © Iain Diack

Relevant case study examples

The Great Fen project
The Great Fen is a 50-year project to create a huge wetland area. One of the largest restoration projects of its type in Europe, the landscape of the fens between Peterborough and Huntingdon is being transformed for the benefit both of wildlife and of people.

Tackling Climate Change-Related Threats to an Important Coastal SPA in Eastern England (TaCTICS). A RSPB project aiming to protect the 12 ha of freshwater marsh and 17 ha of freshwater reedbed at Titchwell from the sea. An important secondary objective is to compensate for the unavoidable loss of the brackish marsh at Titchwell.

Hilgay wetland creation project
This project, managed by the Norfolk Wildlife Trust, will create reedbed habitat on over 60 hectares of former agricultural site near to the village of Hilgay in west Norfolk. This will compensate for reedbed habitat that will eventually be lost due to an increased influx of saline water into freshwater areas at the Trust's Cley Marshes reserve on the North Norfolk Coast.

Bog at Wythburn Head, Cumbria
© Tom Holland

14. Upland flushes, fens and swamps

Climate Change Sensitivity: **Medium**

Introduction

Upland flushes, fens and swamps are sensitive to changes in the quality and quantity of water supply and its seasonal availability, all of which are likely to alter significantly under climate change. Upland flushes, fens and swamps are likely to be less sensitive to changes in temperature as long as precipitation is sufficient to prevent drying out in rain-fed areas and/or periods of summer drought are not too severe (Carey 2013).

The combination of the direct impact of changes to precipitation and temperature, and the indirect impacts of changes in water management and drainage could pose a threat to these habitats.

Habitat Description

Upland flushes, fens and swamps are peat or mineral-based terrestrial wetlands in upland situations, which receive water and nutrients from surface and/or groundwater sources as well as rainfall. The soil, which may be peaty or mineral, is waterlogged, with the water table close to or above the surface for most of the year. The habitat includes both soligenous[6] mires (springs, flushes, valley fens) and topogenous[7] mires (basin, open-water transition and flood-plain fens), as well as certain moor grass *Molinia grasslands* and rush pastures, but excludes ombrotrophic (rain fed) bogs and associated bog pools and seepages (blanket bog priority habitat).

These wetlands tend to occur within more natural habitat settings than in the lowlands, and the transitions between the various habitat components, such as water courses, mires and drier habitats are more in evidence, and external pressures are in general far less pervasive. This provides a greater degree of resilience to these habitats than their lowland equivalents, as well as retaining transitions and many species of lower nutrient systems which have been lost from the lowlands. Some of the component features (e.g. alkaline fens) tend to be small in extent, but most upland areas support fairly extensive valley mire systems that run from hill tops down to limits of enclosure and sometimes beyond. Although they may not be as extensive as other upland habitats, their contribution to the overall biodiversity of the uplands is great, as they tend to be far more species-rich than the habitats they occur within and also provide essential resources to the fauna associated with these surrounding habitats. Usually these are grazed by deer, sheep, or sometimes cattle, in conjunction with surrounding grassland and heath.

These features are often associated with the headwaters of streams and rivers, and in many cases develop around the initial outflows of watercourses. Their maintenance or restoration, where drained or otherwise damaged, plays a key role in supporting the quality and nature of river flow. The potential to restore natural hydrological function in the headwaters of streams, and the benefits this can bring, is great, but is largely unrecognised and unexploited.

Upland flushes, fens and swamps vary, but are typically dominated by sedges and their allies, rushes, grasses (e.g. *Molinia*, and very often a carpet of bryophytes e.g. S*phagnum spp.*, *Cratoneuron spp.*, and a diversity of wetland herbs including marsh valerian *Valeriana dioica*, bog asphodel *Narthecium ossifragum*, marsh violet *Viola palustris*, and grass-of-Parnassus *Parnassia palustris*. Vegetation is generally short (less than 1m and often less than 30cm) but can sometimes be taller in swamps.

6 Water movement is predominantly lateral through the soil or discharging from the rock.
7 Water movement is predominantly vertical and overland, resulting in water ponding in depressions.

The habitat frequently supports a rich flora of vascular plants with many rare species e.g. sheathed sedge *Carex vaginata*, alpine rush *Juncus alpinoarticulatus*, false sedge *Kobresia simpliciuscula*, yellow marsh saxifrage *Saxifraga hirculus* and Scottish asphodel *Tofieldia pusilla*. It is also exceptionally important for bryophytes with notable species including, flat-leaved bog-moss *Sphagnum platyphyllum*, slender green feather-moss *Hamatocaulis vernicosus*, and silky swan-neck moss *Campylopus setifolius*. It is also important as nesting habitat for wetland birds, such as curlew, snipe and grasshopper warbler and supports a rich and diverse invertebrate fauna, which in turn provide an important food source for upland breeding birds at critical times of year.

The habitat is widespread but local throughout the English uplands, although certain types are much more geographically limited. For example, alkaline fens are restricted to areas with an outflow of base-rich water, including the Craven area of Yorkshire, the North York Moors, the southern Lake District, the Shropshire Hills, and Upper Teesdale. Most upland areas support predominantly acidic valley mire systems, such as Dartmoor and Bodmin Moor. In general, this habitat has been poorly surveyed and the full extent of its interest and value is not well known. However, recent work is revealing the scale and richness of the habitat in areas where it has not previously been appreciated, e.g. Callaghan 2012; Tratt, Eades & Shaw 2012; Jerram 2015. The extent of this habitat is difficult to assess because the habitat has not been comprehensively surveyed in many areas, tends to occur in small, sometimes numerous stands and often it merges seamlessly into other upland semi-natural habitats such as heath and bog.

Potential climate change impacts

Cause	Consequence	Potential impacts
Higher mean temperatures	Reduced water quality due to increased nutrient concentration from faster decomposition	■ Higher temperatures will shift the balance of competition towards relatively more southerly species with the potential loss of montane and northern species. ■ Increased nutrient loading could lead to eutrophication and the increased dominance of ruderal plant species.
Altered seasonal rainfall patterns	Increased seasonal variation in water table levels	■ Loss of wetland specialists requiring consistently wet conditions.
Drier summers	Drought	■ Reduced water table, leading to changes in species competition and decreased water quality through the increased release of particulate and dissolved organic carbon during autumn/winter rainfall. ■ Drying out of habitats in summer could lead to the loss of individual species and a shift in community composition. ■ Drying and oxidation of peat, followed by a release of nutrients, will lead to further shifts in community composition. Competition by species more suitable to lower water tables and drier conditions may lead to colonisation by scrub (Holland *et al* 2010). ■ Areas with good water supply may come under increased pressure from livestock, leading to poaching and grazing.
More extreme weather events	Heavy rain	■ Heavy rainfall could lead to increased scour and landslips in and around upland springs.
Global impacts	The policy and economic environment for upland livestock farming, renewable energy and carbon management could change	■ Upland flushes, fens and swamp habitats are often found on land under extensive livestock farming or grouse moor management. Changes of management approach within these systems, which may be climate driven, and could include changes to subsidy payments, may have a greater impact on this habitat than climate change, as they are especially sensitive to grazing and trampling (Holland *et al* 2010).

Adaptation responses

The small size of many sites, sitting within a matrix of other habitats, means that minimising adverse impacts from the management of adjacent habitats will often be the most important adaptation response.

The majority of the high quality examples of the habitat occur in sites of relatively high naturalness, and are part of extensive areas of natural and semi-natural habitats.

The fragmented and isolated nature of these habitats reduces the chances of species moving between habitat patches and increases the risk to small blocks of habitat. Restoration of habitat to increase size and connectivity is therefore a priority.

Some of the potential adaptation options for this habitat are outlined below.

- Remove pressures and encourage restoration of natural hydrological function, e.g. by drain blocking and re-naturalisation of stream and river systems.
- Manage grazing levels and timing to reduce the risk of over grazing, eutrophication and severe poaching.
- Where scrub encroachment becomes a problem, ensure appropriate management to prevent a loss of ground flora.
- The isolated nature of flushes means that the translocation of species from other sites may be a viable adaptation option where natural colonisation is unlikely.

Relevant Countryside Stewardship options

UP3 Maintenance of moorland

This option aims to maintain areas of moorland habitats that are currently in good condition to benefit upland wildlife, retain historic features and strengthen the landscape character. The option can also promote good soil management, which will reduce diffuse pollution.

UP5 Moorland re-wetting supplement

This option will maintain and restore vegetation mosaics, wetland habitats and associated wildlife. If successful there will be improved hydrology of moorland habitats and benefits to upland flora and fauna, e.g. increased sphagnum moss growth will improve breeding habitat for invertebrates, a food source for grouse and wader chicks.

Further information and advice

JNCC (2008) UK BAP habitat description **Upland flushes, fens and swamps**.

Scottish Natural Heritage (2011) **The Fen Management Handbook**
This handbook is produced by Scottish Natural Heritage aims to improve managers' understanding of fens and how they function, to explain why fens need management, and to provide best practice guidance.

Environment Agency **A Wetland Framework for Impact Assessment at Statutory Sites in England and Wales**.
Wetland scientists at the University of Sheffield have developed a way of classifying wetlands based on an understanding of where their water supply comes from and the environmental and landscape conditions in which the wetland has developed. Understanding how a wetland 'works' means that important habitats can be protected, as we can assess where, when and how changes in certain aspects such as groundwater supply and water quality may affect the wetland.

Environment Agency (2010) **Ecohydrological Guidelines for lowland wetland plant communities, 2004,** and Fens and Mires update, 2010. A simplified approach to the methods described above.

Mainstone, C., Hall, R., & Diack, I. (2016). **A narrative for conserving freshwater and wetland habitats in England**. Natural England Research Reports No 064.

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Callaghan, D., (2012). A Survey of flushes on the Long Mynd, Shropshire. Report to Natural England, Telford.

Jerram, R. (2015). Survey of Alkaline Fens in the western Lake District. Report to Natural England, Telford.

Purple moor-grass, New Forest.
© Natural England/Iain Diack

15. Purple moor grass and rush pastures

Climate Change Sensitivity: **Medium**

Introduction

Purple moor grass and rush pasture is highly sensitive to changes in agricultural economics. It is largely marginal land and has, in the past, suffered from both agricultural intensification and abandonment, depending on the economic situation (UK Biodiversity Steering Group 1995). Climate change is likely to increase these pressures, with increased uncertainty and extreme events making it increasingly difficult to manage sites.

In addition, purple moor grass and rush pasture is sensitive to the direct impact of climate change. Being dependent on wet or waterlogged soils, it is sensitive to changes in the water table and flooding, with reduced summer rainfall in particular potentially promoting a change to drier habitats. However, it is likely to be affected less where water supply is from groundwater and where increased winter rainfall leads to greater aquifer recharge.

Habitat Description

Purple moor grass and rush pastures occur on infertile, seasonally-waterlogged sites with slowly permeable, humic or peaty gley, as well as peat soils. The pH range for the component types is wide, ranging from 4.7 (acidic) to 7.4 (alkaline). They occur mostly on flat and gently sloping ground, often associated with valley side springs and seepage lines, but also occur on river and lake floodplains. They tend to be dominated by purple moor grass *Molinia caerulea*, sedges, and jointed rush species, and are usually managed as pasture, or more rarely as hay meadows. Neglect results in dominance by tall herbaceous species (potentially leading to development of tall-herb fen) and ultimately development of wet woodland. They may be very small, for example, a few metres square around a discrete spring, or may form part of larger tracts of semi-natural vegetation with habitats including dwarf-shrub heath, bogs, flushes, tall-herb fens and dry grasslands.

In many cases, fen meadows and rush pasture types occur as isolated, enclosed sites in the farmed lowland landscape, sometimes in association with other grassland types, wetland vegetation including bogs and fens, and wet heath. In the upland fringe and in other areas of high rainfall and impeded drainage, rush pasture is more frequent and more extensive.

Species particularly associated with purple moor grass and rush pastures include: wavy St. Johns- wort *Hypericum undulatum*, meadow thistle *Cirsium dissectum*, marsh hawk's beard *Crepis paludosa*, greater butterfly-orchid *Platanthera chlorantha*, lesser butterfly-orchid *Platanthera bifolia*, marsh fritillary butterfly *Euphydryas aurinia*, small pearl-bordered fritillary *Boloria selene*, narrow-bordered bee hawkmoth *Hemaris tityus*, curlew *Numenius arquata*, snipe *Gallinago gallinago*, and grasshopper warbler *Locustella naevia*.

Potential climate change impacts

Cause	Consequence	Potential impacts
Higher annual average temperatures	Longer growing season	■ Increased plant growth leading to altered management requirements, such as stocking density and grazing periods. ■ Earlier onset of the growing season may lead to less favourable conditions for ground-nesting birds that require short swards.
Hotter summers	Higher evapotranspiration	■ Reduced water tables (see drier summers).
Drier summers	Increased soil moisture deficit	■ Water stress could lead to the loss of individual species and changes in the plant community composition. ■ Drier conditions in late spring could reduce the suitability for breeding waders such as snipe and redshank. ■ Lower water tables could lead to ground conditions becoming suitable for the intensification of grazing or conversion to arable cropping (although this will often be prevented by SSSI or EIA regulations), leading to a direct loss of habitat.
Wetter winters	Increased risk of winter flooding and increased nutrient loading Higher winter water table	■ Increased nutrient inputs from in-washed sediment could lead to enrichment and the loss of nutrient-poor vegetation types. ■ Higher spring soil moisture levels (combined with higher spring temperatures) may increase total biomass and favour more competitive species. ■ Ensuring appropriate levels of grazing may become more difficult.
More extreme events	Summer and Winter flooding	■ More flooding could lead to a shift in species composition to favour those species able to cope with long-term inundation. ■ Increased nutrient input resulting from flooding with nutrient rich water will benefit those species able to utilise enhanced levels, with the potential loss of nutrient-poor vegetation. ■ More frequent disturbance could increase susceptibility to the spread of invasive species (Knight *et al* 2014). ■ More frequent flooding will make it more difficult to maintain appropriate grazing levels and will make access for management more difficult.

Adaptation responses

Purple moor grass and rush pasture requires active management through grazing or cutting, and ensuring the appropriate level of grazing in the face of changing environmental conditions and the changing economics of agricultural production is likely to remain an important adaptive response on many sites.

Removing or reducing pressures on wetlands, including ground water abstraction, drainage and nutrient enrichment, is important to ensure the habitat is in the best possible state to adapt to any climate change impacts. As well as dealing with licensed activities such as abstraction, this will be facilitated by the designation or sympathetic management of larger areas to protect land around wetlands, and improved management of soil and water within catchments. Due the susceptibility of the habitat to changes in water levels, actions to ensure an adequate supply of water to sites will also be important.

In many areas, the remaining areas of purple moor grass and rush pasture sites are highly fragmented, and actions to increase ecological connectivity of remaining patches, by increasing their size and creating new habitat, will be needed to increase resilience.

Purple moor grass and rush pasture communities will alter under climate change, and the extent to which change is accepted and managed will need careful consideration in each location, taking account of the particular circumstances. Where loss of the habitat is anticipated as a result of increased summer flooding, for instance, encouraging the development of the habitat to reflect the new conditions (in the same wetland landscape if possible) should be factored in to long-term planning.

There are various existing initiatives to improve the availability of water and water quality, including the Water Framework Directive (WFD) and the Environment Agency's Restoring Sustainable Abstraction programme. It is critical that any risks from climate change are considered in the context of these, and that actions to improve resilience, as well as current status, are identified and included in relevant programmes and plans, in particular, the WFD River Basin Management Plans, which are updated at five year intervals, and the Water Companies Asset Management Programme (AMP), associated with the five yearly price review.

The requirement for a flexible management regime of grazing and/or cutting that is able to adjust to seasonal variation in rainfall is also important. This will remain a challenge due to the low financial return that management of these habitats provides.

Climate change interactions with nutrient enrichment from atmospheric deposition may accelerate negative change. Efforts to reduce nutrient enrichment from this source will continue to be necessary to maintain or restore favourable condition. Restoring natural hydrological processes on and around wetland sites is likely to improve the resilience of features. This may not always be appropriate, e.g. on sites that have been created and sustained wholly by human intervention, but in most circumstances it should be seriously considered. This, in the first instance, will involve being very clear about site function, existing pressures, and anthropogenic modifications to the wetland. For example, many sites retain artificial drainage networks which have been perpetuated for no reason other than because they have 'always been there'. Consideration should be given to removing these drainage functions unless they are critical to protecting very high value features, infrastructure or property.

Some of the potential adaptation options for this habitat are outlined below:

- Establish an ecohydrological characterisation for the site that considers all aspects of the water regime, reference hydrological state, existing state, pressures and threats, and the feasibility of restoration options, to ensure that any interventions are carried out with full knowledge of the value and function of the site.
- Ensure appropriate management through extensive grazing combined, where required, with scrub management or cutting to ensure that habitats do not develop into rank grassland, scrub or woodland, or conversely, are over-grazed.
- Ensure management is sufficiently flexible to provide appropriate management under a range of growing conditions, for example by making sure alternative land is available for grazing in years when the land is flooded.
- Expand the resource through the restoration of semi-improved pasture and re-creation on improved grassland/arable land. Target this to ensure expansion and linkage of existing sites.
- Increase the heterogeneity of habitats on larger sites by varying the timing and range of management regimes to produce a range of vegetation structures and, where possible, a mosaic of habitat types.
- Locations for the restoration or creation of purple moor grass and rush pasture habitats should be identified at the planning stage of flood management schemes within river floodplains.

Snipe in boggy pasture. © Andy Hay (rspb-images.com)

Relevant Countryside Stewardship options

GS6 Management of species-rich, semi-natural grassland

This option is targeted at the maintenance and protection of areas of species-rich grassland.

GS7 Restoration towards species-rich grassland

This option is targeted at grasslands that are potentially rich in plant and associated animal life. They are often on difficult ground and may have suffered from management neglect or they may have been selected for agricultural improvement. The botanical diversity of such grassland may be enhanced by simply amending existing management practices. However, on many sites pro-active restoration management will be required, involving the introduction of seeds and the creation of gaps for their establishment. Substantial changes of livestock type, timing of grazing or control of dominant species may also be required. The option can also contribute to protecting valued landscapes and archaeology, and the promotion of good soil conditions.

WT12 Wetland grazing supplement

The aim of this supplement is to support a grazing regime where this is the most appropriate form of management for the habitat.

Further information and advice

Centre for Ecology & Hydrology **Wetland toolkit for Climate Change**
The Wetland Toolkit for Climate Change guides the user in the application of tools developed to assess how climate change in the 2050s (2041-2070) might impact on wetland ecohydrology in England and Wales. The guidance and the tools are designed to be used by anyone concerned with the impacts of climate change on wetlands. It is anticipated that the main users will be site managers concerned with the status of their wetlands.

Scottish Natural Heritage (2011) **The Fen Management Handbook**
This handbook produced by Scottish Natural Heritage aims to improve managers understanding of fens and how they function, to explain why fens need management and to provide best practice guidance.

Environment Agency **A Wetland Framework for Impact Assessment at Statutory Sites in England and Wales**.

Environment Agency (2004) **Ecohydrological Guidelines for lowland wetland plant communities, 2004,** and Fens and Mires update 2010.

JNCC (2008) UK BAP habitat description **Purple moor grass and rush pastures**.

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Mainstone, C., Hall, R. & Diack, I. (2016). **A narrative for conserving freshwater and wetland habitats in England**. Natural England Research Reports No 064.

UK Biodiversity Steering Group (1995). Biodiversity: the UK Steering Group Report, **Vol II: Action Plans** HMSO, London.

Blanket bog on Fleetwith Pike, Cumbria
© Natural England/Paul Glendell

16. Blanket bog

Climate Change Sensitivity: **Medium**

Introduction

Blanket bog is an upland habitat that forms in situations with high rainfall, low evapotranspiration and flat or gently sloping land. Healthy blanket bog, with actively growing mire species particularly *Sphagnum* mosses, accumulates peat, but large areas of blanket bog in England are in a degraded condition because of a combination of drainage, burning, overgrazing and atmospheric deposition.

Changes to seasonal rainfall patterns and/or an increased frequency of summer droughts may destabilise blanket bog systems. Climate envelope modelling suggests that a large proportion of British peat bogs are on the edge of their climatic limits (Clark *et al* 2010; Gallego-Sala *et al* 2010; House *et al* 2010). However these models do not take account of the biological processes that take place within blanket peat. Analysis of the pollen archive within blanket peat shows that over the course of the life of blanket bog to date, the plant species that have been dominant at any given time has varied (e.g. Tallis, 1964a, 1964b). This variation is likely to reflect human activity, the different environmental conditions that have occurred over the last 3,000-5,000 years, and the more recent changes in atmospheric deposition associated with industrialisation. There is therefore potentially a degree of resilience to climate change at least in the short – medium term.

Blanket bogs receive their water from rainfall, although it is the number of rain-days that is important rather than just the volume of rain, together with the low rates of evapotranspiration associated with high cloud cover. Changes in the chemistry of rain, for example increases in nitrogen, allied with changes in climate, may lead to changes in the plant species present or the way in which they grow (Caporn & Emmett 2009).

The interaction of climate change and land management is important, as damage or changes to vegetation cover can have significant implications for the long-term stability of the ecosystem. Many areas of blanket bog display features that are the legacy of past and current management (including drainage and burning) and atmospheric deposition, and are therefore degraded (Worrall *et al* 2010). This increases their vulnerability to climate change.

Habitat Description

English blanket bogs occur at relatively high altitude, with a minimum of 160 days of rain per year and an annual rainfall of at least 1200mm (Rodwell, 1991). By contrast, the low-lying blanket peats of Ireland and western Scotland have a requirement for a similar minimum rainfall but around 200 rain days per annum (O'Connell, 1990). It is the waterlogged, acidic conditions that result from this environment that leads to the formation of peat, through the partial decomposition of *Sphagnum* mosses and associated plants. The formation of peat occurs across the landscape, and from this is derived the term 'blanket bog'.

Typical blanket bog species include cross-leaved heath *Erica tetralix*, deer grass *Trichophorum cespitosum*, cotton grass *Eriophorum* species, and bog-moss *Sphagnum* species. The relative proportion of these species varies between geographic areas and reflects past and current land use, management, and historic atmospheric deposition. Damaged and degraded bogs may be dominated by heather *Calluna vulgaris* or purple moor grass *Molinia caerulea*, and in these situations, typical bog species may be infrequent or absent.

Blanket bog is an important nesting or feeding habitat for upland bird species, including hen harrier *Circus cyaneus*, merlin *Falco columbarius*, golden plover *Pluvialis apricaria*, dunlin *Calidris alpina schinzii* and short-eared owl *Asio flammeus*. It is also important for a small number of specialist species with localised or very restricted distributions (Webb *et al* 2010).

Blanket bog is one of the most extensive semi-natural habitats in the UK. It is found from Devon in the south-west of England to Shetland in the north of Scotland. The largest areas of blanket bog in England are found in the Peak District and the North Pennines. The Bowland Fells also contain significant areas, as does Northumberland. Smaller areas are located in the Lake District and the North York Moors. The total area of blanket bog in England is estimated to be 244,536 ha.

Potential climate change impacts

Cause	Consequence	Potential impacts
Increased mean temperatures	Longer growing season	■ Peat forming mire vegetation may become less dominant, but this is likely to be determined by the hydrological conditions on any given site and the pattern of rainfall. ■ Bracken may become invasive in areas of degraded peat, and at higher altitudes (Carey 2013). ■ Warming may interact with increased nitrogen deposition leading to changes in plant species and communities.
Hotter summers	Increased evapotranspiration	■ A reduced water table could lead to changes in species composition and an increase in the release of particulate and dissolved organic carbon during autumn and winter rainfall, leading to reduced water quality.
Drier summers	Drought Drier ground conditions	■ More frequent droughts could affect vegetation community composition, with a possible shift in the dominance of specialist species, and hummock species becoming dominant over hollow species. ■ Increased oxidation rates and wind-blow of existing bare peat. ■ Peat will become more susceptible to damage under wildfire or managed burns, especially where degraded blanket bog is dominated by heather or grasses such as purple moor-grass *Molinia*. ■ Improved accessibility for visitors could lead to increased erosion and incidence of wildfires. ■ Areas of peat particularly on moorland edges may be subject to higher stocking levels.
Wetter winters	Increased surface water run-off	■ Areas of blanket peat may become less stable, especially where subjected to stress from track construction, excavation or burning, increasing the risk of peat slides, bog bursts and erosion. Greater run-off could also lead to an increase in the release of particulate and dissolved organic carbon.
Storm events	Increased rainfall intensity	■ Heavy rainfall and more surface water will increase problems of gullying where erosion features already exist.
Combined	Potential changes to the economics of upland grazing and shooting systems	■ An increase in the intensity of livestock grazing could lead to vegetation community change and/or mechanical damage to the peat. ■ Changes in red grouse populations or burning regimes could affect blanket bogs.

Adaptation responses

A large proportion of blanket bogs are already degraded as a result of draining, burning (managed burning and wildfire), over grazing and atmospheric pollution. Many blanket bogs are now relatively dry and may already have lost the peat forming species such as *Sphagnum* mosses, which may have been replaced by other species such as heather and moor grass. In these cases, active restoration, including by grip-blocking and re-vegetation of bare peat, will be the most important adaptation measure. This is especially important as the resilience of bogs to environmental change has been shown to increase if *Sphagnum* cover can be maintained (Gallego- Sala & Prentice 2012).

Bogs are dependent on a reliable high water table, and in the longer term, as climate change progresses, actions that improve both the quantity and quality of water held on sites will become increasingly important.

The restoration of blanket bogs has multiple benefits. It increases the resilience of the habitat to climate change and improves the delivery of other ecosystem services such as carbon sequestration and drinking water provision. These systems therefore represent an ideal opportunity to involve stakeholders in planning work at a catchment scale.

In the longer term, it may become increasingly difficult to maintain active blanket bog in more climatically marginal areas. Habitat restoration and appropriate management to increase resilience remain a priority for designated sites, but may need to be reviewed in future.

Some of the potential adaptation options for this habitat are outlined below.

- Adapt land management regimes, for example by avoiding burning and ensuring appropriate livestock and stocking regimes, to prevent further habitat degradation and encourage the restoration of 'active' blanket bog with peat forming processes.
- Re-vegetate areas of bare peat, using best practice restoration techniques and appropriate plant species mixes. Initially, this should help to prevent or reduce further peat loss, but in the longer term will help to restore 'active' blanket bog.
- Restore natural hydrological regimes through drain and gully blocking and re-profiling, using best practice techniques.
- In regions where climate change may have an especially marked effect on blanket bog processes, such as parts of the Peak District and the North York Moors, identify areas likely to retain the hydrological regime required for bog development and ensure these are protected and are under optimal management.
- Identify areas where the hydrological regime is currently, or in the future may be, sufficiently impaired to prevent bog development, and determine the most appropriate alternative objectives. This might involve retaining a high water table for as long as possible to maintain ecosystem services such as carbon storage and water management.

Hare's-tail cottongrass, an important plant of peat bogs. © Natural England/Peter Roworth

Relevant Countryside Stewardship options

UP3 Management of moorland

This option aims to maintain and restore moorland priority habitats and ecosystem function, species, protect historic features and strengthen landscape character.

Further information and advice

Peak District National Park (2011) Information brochure **Blanket Bog**.

Cumbria Wildlife Trust information brochure **Blanket Bog**.

Climate Change and the British Uplands Climate Research - Vol. 45 (2010).This Climate Research special edition on climate change and the British uplands presents a synthesis of current knowledge to help inform policy decisions about safeguarding ecosystem service provision. Topics covered include changing upland climates, mapping blanket peat vulnerability to climate change, measuring and modelling change in peatland carbon stocks, and managing upland ecosystem services under a changing climate.

Natural England (2013) **Restoration of degraded peat bog** NEER003.

IUCN UK Committee 2011, **Commission of inquiry on peatlands**. The Commission of Inquiry on Peatlands, part of the **IUCN peatland programme**, brought together experts in science, policy and practice to carry out a thorough review of peatland issues and a deliver clear scientific consensus about peatland restoration, particularly in relation to climate change, biodiversity and ecosystem services.

Defra **Compendium of UK peat restoration and management projects in uplands and lowlands** Study undertaken for Defra in 2007/8.

JNCC (2008) UK BAP priority habitat description **Blanket Bog**.

Key evidence documents

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Burt, T.P., & Holden, J. (2010). Changing temperature and rainfall gradients in the British Uplands. *Climate Research* 45, 57–70.

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Gallego-Sala, A.V., & Prentice, I.C. (2012). Blanket peat biome endangered by climate change. Nature Climate Change, September 2012

Natural England 2013, **Review of upland evidence**. Series of evidence review papers covering a range of upland habitats and issues.

O'Connell, M., 1990 Origins of Irish lowland blanket bog. In G.J., Doyle (Ed). *Ecology and Conservation of Irish Peatlands* Dublin, Royal Irish Academy.49-71.

J.S. Rodwell, (ed). 1991 *British Plant Communities Vol. 2: Mires and heaths*. Cambridge, CUP

Tallis, J.H. 1964a. Studies on Southern Pennine Peats. I. The General Pollen Record. *Journal of Ecology*, 52, 323 - 331.

Tallis, J.H. 1964b. Studies on Southerm Pennine Peats. III The Behaviour of Sphagnum. *Journal of Ecology*, 52, 345 – 353.

Walking-the-Talk (2011). Paths and climate change - an investigation into the potential impacts of climate change on the planning, design, construction and management of paths in Scotland. Scottish Natural Heritage Commissioned Report No. 436.

Webb, J.R., Drewitt, A.L. & Measures, G.H. (2010). Managing for species: Integrating the needs of England's priority species into habitat management. Part 1 Report. Natural England Research Reports, Number 024.

Worrall F., Chapman P., Holden J., Evans C., Artz, R., Smith P. & Grayson R, (2010) **Peatlands and Climate Change**. Scientific Review, 15pp, IUCN.

Worrall F, Reed M, Warburton J, Burt TP (2003) Carbon budget for British upland peat catchment. *Sci Total Environ*, 312,133–146.

Lowland raised bog, Duddon Mosses NNR, Cumbria.
© Natural England/Jacqueline Ogden

17. Lowland raised bog

Climate Change Sensitivity: **Medium**

Introduction

An intact, fully functioning lowland raised bog is expected to be relatively resilient to projected climate change, although both changes to patterns of rainfall, including extreme events and summer warming, will place increasing pressure on the habitat. In England, however, there are no raised bogs in this condition.

The impact of historic and current land management has a significant impact on the vulnerability of sites. Damage through peat cutting or drainage (both on and off-site) that alters the hydrology of sites has significant adverse impacts on the ability of the bog to withstand reduced rainfall and extreme events such as drought. Degraded bogs are also more vulnerable to climate change impacts on the quality and quantity of ground water.

In England, most remaining lowland raised bog habitat is found on the central or core area of the original dome. Surrounding this is an area of degraded peatland, often now under alternative land use, making the remaining bog increasingly vulnerable to off-site impacts and land-use change.

Habitat Description

Lowland raised bogs are peatland ecosystems which develop primarily in lowland areas such as at the head of estuaries, along river flood-plains and in topographic depressions. In such locations drainage has been impeded by a high groundwater table or by low permeability of the substrata. The resultant water-logging provides anaerobic conditions which slow down the decomposition of plant material, which in turn leads to an accumulation of peat. This accrual of peat, with its *Sphagnum* moss surface, over time, elevates the bog surface above groundwater levels to form a gently-curving dome from which the term 'raised bog' is derived.

In England, lowland raised bogs are a particular feature of cool, rather humid, regions such as the north-west lowlands, but remnants also occur in some southern and eastern localities, for example in Somerset, South Yorkshire, Sussex and the Fens.

The accumulation of peat separates the bog surface from the influence of groundwater, so that it becomes irrigated exclusively by rainfall and is termed 'rain-fed'. Consequently, the surface of a 'natural' lowland raised bog is typically waterlogged, acidic and deficient in plant nutrients. This gives rise to a distinctive suite of vegetation types, which although low in overall diversity, support specialised plant assemblages dominated by a range of *Sphagnum* mosses, as well as vascular plants adapted to waterlogged conditions such as the cotton grasses *Eriophorum spp.* Lowland raised bogs also support rarer plants such as the bog mosses *Sphagnum pulchrum* and *Sphagnum imbricatum*, as well as a number of higher plants which have become increasingly scarce in the lowlands, including bog rosemary *Andromeda polifolia*, great sundew *Drosera anglica*, and cranberry *Vaccinium oxycoccos*.

The raised bog surface may support a patterned mosaic of pools, hummocks and lawns; a micro-topography created in part by the growth of the plants themselves. This provides a range of water regimes which support different species assemblages. *Sphagnum* mosses are the principal peat-forming species in lowland raised bogs, and their dominance in the living vegetation layer gives a bog its characteristically 'spongy' surface. The ability of this layer to store water is critical in keeping the bog surface wet during the summer.

A number of plant communities can be found on raised bogs. Plant communities that are typical of natural raised bogs include the bog pool communities, raised and blanket mire. In addition, a number of communities, including *Scirpus cespitosus - Erica tetralix* (deer grass-cross-leaved heath) wet heath; *Calluna vulgaris - Eriophorum vaginatum* (common heather-cotton grass) blanket mire; *Eriophorum vaginatum* (cotton grass) blanket and raised mire; *Molinia caerulea - Potentilla erecta* (purple moor grass-Tormentil) mire; and *Betula pubescens - Molinia caerulea* (birch-purple moor grass) woodland, can be found on raised bogs which have been subject to some disturbance such as drainage or peat-cutting.

Lowland raised bogs also support a distinctive range of animal species, including a variety of breeding waders and wildfowl, as well as invertebrates. Rare and localised invertebrates such as the large heath butterfly *Coenonympha tullia*, the bog bush cricket *Metrioptera brachyptera*, and mire pill beetle *Curimopsis nigrita* are found on some lowland raised bog sites.

There has been a large decrease in the area of lowland raised bog. The area of lowland raised bog in England retaining a largely undisturbed surface is estimated to have declined from around 37,500 ha to 500 ha since the start of the nineteenth century.

Round-leaved Sundew Drosera rotundifolia, Dersingham Bog, Norfolk. © Natural England/Allan Drewitt

Potential climate change impacts

On fully functioning intact bogs, climate change modelling suggests that many of the dominant species will remain relatively unaffected by projected climate change (Berry & Butt 2002), as when in good condition lowland raised bogs are self-controlling systems. However, most English lowland raised bogs are vulnerable because they have been drained. Their surfaces are at risk from drying out, leaving them more prone to erosion, the effects of drought, and fire damage.

The table below highlights the potential climate change impacts to English lowland raised bogs, all of which are degraded in some manner.

Cause	Consequence	Potential impacts
Increased mean temperatures	Longer growing season	■ Bog vegetation may become less dominant. Change is likely to be influenced by the interaction with the hydrological conditions on any given site and the pattern of rainfall.
Hotter summers	Increased evapotranspiration	■ A reduced water table could lead to a potential increase in purple moor-grass *Molinia caerulea* and/or heather *Calluna vulgaris* and silver birch *Betula pendula*, which will intercept rainfall, increase transpiration and encourage the development of flow paths associated with root systems. ■ Already degraded bogs will be more vulnerable than intact bogs, and are more likely to suffer from drying out, which in turn will impair the natural hydrological regime and the ability of the *Sphagnum* carpet to persist.
Drier summers	Drought	■ Water table draw down will become more marked in the future, especially in the east and south. ■ Altered vegetated community composition, with a possible shift in the dominance of specialist species. ■ Increased oxidation rates and wind erosion of existing bare peat. ■ Increased fire risk, especially where degraded bog is dominated by heather or grasses such as purple moor-grass *Molinia*. ■ Peat will become more susceptible to accidental fire damage.
	Drier ground conditions	■ Improved accessibility for visitors could lead to increased erosion and incidence of wildfires.
Wetter winters	Increased surface water run-off	■ Increased run-off could lead to increased erosion in bogs with degraded hydrology, and an increased risk of bog-burst (bog-slide, bog flow), where wet peat can slide sideways off the raised dome.
Storm events	Increased rainfall intensity	■ Heavy rainfall and more surface water will intensify problems of erosion.
Combined		■ Lowland raised bogs are more vulnerable when their hydrology has been degraded and the surface dries out, leaving them more prone to erosion, the effects of drought, and fire damage. ■ Most remaining bogs are small and isolated, meaning that the populations they support are at greater risk of local extinction due to reduced interchange of populations.

Adaptation responses

As already stated, a large proportion of lowland raised bogs are degraded as a result of cutting, drainage, over grazing and atmospheric pollution. In all cases, this results in bogs ceasing to function as rain-fed systems, increasing their vulnerability to changes in ground water quantity and quality. In these cases, active restoration of the hydrology to reduce the reliance on ground water, through actions to improve the water retention of the site, will improve the resilience to both climatic and non-climatic drivers. Restoration activity is nearly always constrained by ingress of other land use. A fully functioning raised bog will need restoration out to the edge of the peat body or the installation of an appropriate hydrological barrier.

Bogs are dependent on a reliable high water table, and in the longer term, as climate change progresses, actions that increase the water table and water retention on sites will become increasingly important. The restoration of lowland raised bogs has multiple benefits. It increases the resilience of the habitat to climate change and improves the delivery of other ecosystem services, such as carbon sequestration and flood risk management.

In the longer term, it may become increasingly difficult to maintain active blanket bog in more climatically marginal areas in the south and east. However, habitat restoration and appropriate management to improve resilience should remain a priority, but should be kept under review.

Potential actions

- Cease peat cutting and ensure optimum management is in place to eliminate damage to bog surfaces by machinery or other means. Over-grazing by livestock can lead to poaching, compaction, surface contamination, and loss of grazing-sensitive plants. At the other extreme, a lack of grazing, coupled with drier conditions, on raised bogs usually favours widespread expansion of bracken, tall heather, birch and pine.
- Develop a full understanding of the hydrology and define the functional boundaries of the site.
- Restore natural hydrological regimes and high water tables through blocking or re-profiling drains to encourage the growth of *Sphagnum*. Where the surface is either complex or very open and featureless, e.g. after peat milling, water may need to be penned, for example through extended pile or peat bunds.
- Where sites may have dried out and been colonised or planted with trees, remove up to 95% of native trees, and all invasive non-native species. After extraction, keep water levels raised to reduce re-colonisation, as evapotranspiration from trees and scrub will exacerbate drying effects.
- Review the hydrology of land surrounding the site to identify off-site drainage impacts, and also consider pressures such as abstraction, pollution and nutrient enrichment. Take action to reduce adverse impacts, for example through the creation of wetland to buffer the core area, or by diverting drains.
- Following restoration of the hydrology, re-vegetate areas of bare peat using best practice restoration techniques and appropriate plant species mixes. Initially, this should help to prevent or reduce further peat loss, but in the longer term will help to restore active peat formation.
- Identify areas where the hydrological regime is currently, or in the future may be, sufficiently impaired to prevent bog development, and determine the most appropriate alternative objectives. This might involve retaining a high water table for as long as possible to maintain ecosystem services such as carbon storage and water management.
- Use or develop a full understanding of the hydrology and extent of peat to determine whether the area of lowland raised bog could be expanded through habitat restoration or creation.

Relevant Countryside Stewardship options

WT10 Management of lowland raised bog

This option supports the maintenance of water levels at the surface of the bog fed only by rainfall. It also requires the control of scrub and other undesirable species and the maintenance of structures required to control water levels.

Where appropriate, the following supplements can be used to support the grazing and cutting of lowland raised bogs.

WT12 Wetland grazing supplement

This option supports the appropriate grazing management of wetland habitats.

WT11 Wetland cutting supplement

Options to raise the water table and encourage appropriate land management on land surrounding the bog may also be appropriate.

Further information and advice

IUCN Peatland Programme - **Climate change mitigation and adaptation potential**.

JNCC (2011) **Towards an assessment of the state of UK peatlands**. Report 445.
This report assesses the state of the UK peatlands, based on available information on the extent, location and condition of peat soil and peatlands, vegetation, land cover, land use, management and a range of environmental influences.

Evans, C., Worrell, F., Holden, J., Chapman, P., Smith, P. & Artz, R. (2011). **A programme to address evidence gaps in greenhouse gas and carbon fluxes from UK peatlands**. Report 443.
This report provides the proposed structure for a measurement programme to improve quantification of the carbon and greenhouse gas fluxes to and from UK peatlands, and allow for the development of more robust UK emission factors for peatland areas.

Worrall, F., Chapman, P., Holden, J., Evans, C., Artz, R., Smith, P. & Grayson, R. (2011) **A review of current evidence on carbon fluxes and greenhouse gas emissions from UK peatlands**. Report 442.
This review considers the current evidence on carbon and greenhouse gas fluxes from UK peatlands under differing land management states, to identify the additional evidence needs required to generate robust emission factors for UK peatlands.

Yorkshire Peat Partnership (2014). **Conserving Bogs - The Management Handbook**. A practical manual to the methods and techniques to effectively manage and conserve bogs. Second Edition.

Relevant case studies

Improving Habitat Management: restoring a lowland raised bog at Blawhorn Moss National Nature Reserve, Central Scotland.
A case study of the transformation of Blawhorn Moss National Nature Reserve (NNR) - a lowland raised bog in the central belt of Scotland that demonstrates how improving habitat management can increase a bogs resilience to climate change.

Restoration of degraded peat surfaces and cut peat faces : Glasson Moss SSSI.
The South Solway Mosses SAC is a Lowland Raised Bog, designated for Active Raised Bogs and Degraded raised bog still capable of natural regeneration. This project aimed to restore cut over degraded peat surfaces and cut peat faces covering 1.3ha.

Key evidence documents

Aerts, R., Wallén, B. & Malmer, N. (1992). Growth-limiting nutrients in *Sphagnum*-dominated bogs subject to low and high atmospheric nitrogen supply. Journal of Ecology, 80, 131–140.

Berry, P.M. & Butt, N. (2002). **Climate change impacts on raised peatbogs: a case study of Thorne, Crowle, Goole and Hatfield Moors**. English Nature Research Reports Number 457.

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Dorset heaths
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18. Lowland heathland

Climate Change Sensitivity: **Medium**

Introduction

Lowland Heathland is sensitive to changes in hydrological conditions and the frequency of fires that may result from higher temperatures and more frequent droughts. Heathland is also sensitive to potential indirect impacts of climate change such as increased recreational pressure. Coastal and dune heathlands may be lost if sea levels rise significantly. Future warmer temperatures, in addition to current increased nutrient availability, could cause grass species to become more dominant, leading to a shift from heathland to acid grassland. Some heathland species currently restricted to southern England are likely to benefit from climate change, including the Dartford warbler *Sylvia undata* which has already expanded its range. The fragmented nature of many heathland sites will increase their vulnerability to climate change.

The ability to undertake winter restoration and maintenance work such scrub or tree clearance may be affected as birds nest earlier in the spring, and the window of opportunity when weather conditions are suitable for controlled burning may narrow. More frequent extreme weather events such as flooding could also impact on winter maintenance.

Habitat Description

Lowland heath developed following prehistoric woodland clearance, and has been kept open through the centuries by grazing, burning and cutting. As the economic value of these uses declined, a considerable area of heath was lost to agriculture, forestry, housing, mineral working and other uses. Heathland is described as a broadly open landscape on impoverished, acidic mineral and shallow peat soil, which is characterised by the presence of heathers and gorses at a cover of at least 25%. It includes both wet and dry heath, usually below 250 metres.

Lowland heath grades into upland heath but is defined by the upper limit of agricultural enclosure and typically supports a range of birds, reptiles and invertebrates not found on upland heath.

Areas of heathland in good condition should consist of an ericaceous layer of varying heights and structures, plus some or all of the following additional features, depending on environmental and/or management conditions: scattered and clumped trees and scrub; bracken; areas of bare ground; areas of acid grassland; lichens; gorse; seasonally wet areas; bogs and open water. Lowland heathland can develop on drift soils and weathered flint beds over calcareous soils (limestone or chalk heath). Lowland heathland is a dynamic habitat which undergoes significant changes in different successional stages, from bare ground (e.g. after burning or tree clearing) and grassy stages, to mature, dense heath.

Lowland heath occurs across a variety of areas of lowland England, and includes the distinctive heaths of Cornwall, Devon and Dorset, those across Hampshire, Surrey and Sussex, the eastern heaths of the Suffolk coast, Breckland and Norfolk, parts of Staffordshire, Sherwood Forest in Nottinghamshire and The Vale of York. There are small heathland sites in other parts of the country too. The total area of lowland heath in England is approximately 70,000 ha.

Potential climate change impacts

Cause	Consequence	Potential impacts
Increased mean temperatures	Longer growing season	■ Dwarf shrub may become less dominant as other more competitive plants become established. ■ Increased nutrient cycling and insect herbivory could cause grasses to become dominant over dwarf shrubs (Ukreate 2006; Wessel *et al* 2004). ■ Increased length of growing season, and activity period of key species, means a reduced window of opportunity to conduct winter management, such as controlled burning and cutting. ■ Changes in soil biota (Haugwitz *et al* 2014).
Hotter summers	Increased evapotranspiration Potential for increased visitor numbers Increased risk of wildfire	■ Drying of sites may cause a change in balance of species, particularly on wet heathland areas. ■ Loss of habitat structural diversity and species changes, leading to risk of local-scale species extinction (Brys *et al* 2005). ■ An increase in unmanaged access could lead to more erosion on access routes, irreversible damage to vegetation and increased risk of wildfires (Albertson *et al* 2010), and increased disturbance of ground nesting birds (e.g. Underhill-Day 2005). ■ Climate change may have an impact on the amount of carbon stored or emitted from heathlands, as well as increasing fire risk (Alonso *et al*, 2012).
Warmer winters		■ Scarce heathland species such as Dartford warbler or invertebrates (Thomas *et al* 2015) could benefit from the warmer conditions. ■ Grass species could become more dominant as a result of increased nutrient availability, leading to a shift from dry heath to acid grassland (Wessel *et al* 2004; Jones *et al* 2015). ■ Bracken could have a competitive advantage over slower growing heather species, leading to changes in community composition (Chapman *et al* 2009, Aspden *et al* 2013). ■ Changes in soil biota (Haugwitz *et al* 2014).
Drier summers	Drought	■ Altered community composition. ■ Drying out and loss of wet heath (Carey 2013). ■ Increased susceptibility to wildfires, and risk of resulting peat/soil damage. ■ Surface peat (especially bare peat) could dry out and be vulnerable to wind blow. ■ Wet heathland species such as *Erica tetralix*, could be threatened because of its need for permanently moist conditions (Carey 2013). If lost it may be replaced with other *Erica* species.
Wetter winters	Increased surface runoff Increase nitrogen deposition	■ Loss of habitat, or water-logging of some areas not normally adjusted to these conditions. ■ Increased vegetative growth (Britton *et al* 2001). ■ Loss of nutrient poor specialist species in favour of more competitive generalists such as grasses (Wessel *et al* 2004). ■ The atmospheric deposition of Nitrogen increases the sensitivity of heather to drought, frost, and heather beetle outbreaks. ■ Reduced opportunity for winter management, such as controlled burning and cutting.
In combination		■ Growth of grasses and the loss of more characteristic plant species will be detrimental for some typical animal species. Key species currently at the northern end of their range such as the smooth snake and sand lizard may benefit as the climate becomes milder (Dunford & Berry 2012). ■ Loss of typical heathland landscapes.

Adaptation responses

Heathland is threatened by many pressures that are not related to climate change, such as habitat loss and an associated increase in fragmentation and isolation, heavy access and recreation pressure, and lack of appropriate management. Increasing the resilience of the remaining areas of heathland by reducing these pressures is likely to be a key adaptive response in many cases. Tree cover in the right places can provide wildlife benefits and reduce fire risk as broadleaved species are less flammable than heathland vegetation. This needs to be balanced against the loss of heathland species, and tree cover should be kept below 15% to maintain favourable condition.

Different aspects of climate change will interact and have different impacts on the various components of heathland systems. Management of existing sites will need to be flexible, and be adjusted to reflect these changes.

In addition to actions on existing areas of heathland, adaptation will also benefit from targeted habitat restoration and creation to address historic habitat loss and to improve the resilience of heathland networks.

Some of the potential adaptation options for this habitat are outlined below.

- Ensure optimal management through a combination of grazing, cutting and/or burning to achieve a diverse vegetation structure.
- Adapt the intensity of management to changing growth characteristics of the heathland, for example by increasing grazing pressure or burning/cutting cycles. More intensive management may be required to maintain condition.
- Ensure fire contingency plans are in place. These may include changes in the design and management of habitats to reduce fire risk, such as firebreaks, fire ponds and the closure of some areas at times of high fire risk.
- Ensure sufficient management capacity to be able to respond flexibly to changing conditions, such as a reduced window for winter management, and wetter conditions preventing winter operations.
- Consider maintaining broadleaved (not conifer) woodland in localised areas to provide a firebreak or a buffer next to urban areas.
- Within sites, identify areas that might act as potential refugia to climate change, such as areas with north facing slopes, complex micro-topography, robust hydrology and high species diversity, and ensure that these are under optimal management.
- Maintain structural diversity in the vegetation to provide a wide range of micro habitats and niches, including, where possible, bare ground, areas dominated by mosses and lichens, herbs, dwarf shrubs of diverse age classes, wet heath and mire, and scattered trees and shrubs.
- Ensure hydrological conditions are fully conserved, for example through blocking artificial drainage and reducing abstraction pressure.
- Increase the area of existing habitat and reduce the effects of fragmentation through targeted re-creation and restoration around existing patches, to increase the core area and reduce edge effects.

Ponies grazing heathland. Sutton Common, Surrey. © Natural England/Paul Greenhalf

Relevant Countryside Stewardship options

LH1 Management of lowland heathland

This option is designed to encourage the appropriate management of existing lowland heathland, both in sites in good condition and in those not currently in good/favourable condition, including on sites whose management has been neglected. Such sites may have become degraded by scrub, bracken, gorse, invasive grasses or secondary woodland encroachment, and in some cases overgrazing and too frequent burning.

This option will benefit the environment by creating a diverse mosaic of vegetation, allowing all heathland types (such as wet or dry heath, transitional heaths, acidic mires and coastal heaths) to flourish. This includes pioneer heath and bare ground, which benefits rarer invertebrates, birds, reptiles and plants. The cover of undesirable species will be low and species that increase when undermanaged (bracken, trees, dense grass tussocks) kept under control. Locally characteristic plant communities and the species they support (such as nightjar *Caprimulgus europaeus*, woodlark *Lullula arborea*, smooth snake *Coronella austriaca*, and sand lizard *Lacerta agilis*, where within their range) are common.

LH2 Restoration of forestry areas to lowland heathland

This option aims to encourage the restoration of lowland heathland on existing or previously forested land. It is most likely to apply to conifer plantations which show evidence of heathland vegetation in forest rides or other open areas. Soil type, management history and location in relation to existing heathland sites will be significant factors in determining suitability. Significant site clearance and weed control may be needed, but it is expected that, following suitable treatment, heathland vegetation will re-establish without the need for seeding from external sources. Clear-felling forestry and the reintroduction of traditional grazing will help to restore areas of heathland, along with its associated wildlife, and will strengthen the vegetation mosaics characteristic of lowland landscapes.

This option will benefit the environment by re-establishing lowland heathland on forested land or land recently (since 1900) colonised by woodland. The area will have a tree cover under 15%, with a diverse mosaic structure and composition, including undisturbed bare ground and varied heathland vegetation types. Locally characteristic plant communities and the species they support (such as nightjar, woodlark, smooth snake or sand lizard) will successfully colonise the site, if within their range.

LH3 Creation of lowland heathland from arable or improved grassland

This option aims to encourage the creation of lowland heathland on arable or improved grassland sites that have effectively lost their heathland seed bank. Soil type, management history and location in relation to existing heathland sites will be significant factors in determining suitability.

Keys to success will include: controlling the availability of soil nutrients, providing a suitable seed source, achieving adequate establishment and controlling undesirable species. Subsequent management by a combination of grazing, or cutting and removal, will be required. The creation of heathland from arable or improved grassland will help to re-create and strengthen the vegetation mosaics characteristic of lowland landscapes.

This option will benefit the environment by creating heathland mosaics with lowland acid grassland, on arable or improved grassland sites that have largely lost their heathland seed bank. Locally characteristic plant communities and the species they support (such as nightjar, woodlark, smooth snake or sand lizard) will colonise the site, if it's within their range.

Further information and advice

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Heather and gorse. Dunkery and Horner Woods NNR
© Natural England/Paul Glendell

19. Upland heathland

Climate Change Sensitivity: **Medium**

Introduction

Projected changes in temperature are likely to drive changes in community structure and species composition, with upland heaths progressively becoming more like present lowland heaths. This will however be moderated by the greater wetness of the uplands (Carey 2013), particularly in the North West. Wet upland heaths will, however, be susceptible to changes in precipitation, especially during the summer.

The large size of upland heath patches within the uplands, together with the high variability in topography and mosaic of habitats will provide some resilience to climate change. Fragmentation and isolation of upland heathlands is less of an issue than for lowland heath, but less mobile species will still be restricted to their original sites. These may become less suitable for many species, particularly those at lower altitudes and in the south. The rate of colonisation by distinctive lowland heath species will depend on the proximity of seed sources, and may be slow given the fragmented distribution of much lowland heath.

Upland heathland is a component of management systems maintained as part of extensive livestock farming or grouse moor management, and changes in approach within these systems (including subsidy payments) are likely to have a greater impact than climate change will directly. Nonetheless, the importance of management by extensive grazing and burning means that upland heaths will be sensitive to indirect impacts of climate change, through changes in policy and the economics of upland grazing systems and carbon management. Certain sites may also be vulnerable to potential increases in visitor numbers, although this is likely to be limited to popular and accessible sites.

Habitat Description

Upland Heathland is found on impoverished, acidic mineral and shallow peat soil, and is characterised by the presence of dwarf shrubs such as heather and gorse (at a cover of at least 25%). Upland heathland is defined as lying below the alpine or montane zone (at about 600-750m) and above the upper edge of enclosed agricultural land (generally at around 250-400m). Blanket bog and other mires, grassland, bracken, scrub, trees and woodland, freshwater and rock habitats frequently form intimate mosaics with heathland vegetation in upland situations.

Upland heath is typically dominated by a range of dwarf shrubs such as heather C*alluna vulgaris*, bilberry *Vaccinium myrtillus*, crowberry *Empetrum nigrum*, bell heather *Erica cinerea*, and, in the south and west, western gorse *Ulex gallii*. In northern areas, juniper *Juniperus communis* is occasionally seen above a heath understorey. Wet heath is most commonly found in the wetter north and west and is dominated by mixtures of cross-leaved heath *Erica tetralix*, deer grass *Scirpus cespitosus*, heather and purple moor-grass

Molinia caerulea, over an understorey of mosses, often including carpets of *Sphagnum* species. Blanket bog vegetation may also contain substantial amounts of dwarf shrubs, but in a healthy state it is waterlogged much of the time and peat-forming, with frequent hare's-tail cotton-grass *Eriophorum vaginatum* and characteristic moss species, particularly *Sphagnum* species. However, in much of the UK it is degraded as a result of drainage, burning and over-grazing and is not actively peat forming. In these circumstances, where there is little or no *Sphagnum* and peat formation has stopped, the vegetation grades into heathland. Underlying peat, typically more than 0.4 m deep, indicates that a site was formerly blanket bog. High quality heaths are generally structurally diverse, containing stands of vegetation with heather at different stages of growth. Upland heath in 'favourable condition' also usually includes areas of mature heather.

Upland heath is associated with important bird of prey species such as hen harrier *Circus cyaneus*, merlin *Falco columbarius*, peregrine falcon *Falco peregrinus*, and short-eared owl *Asio flammeus*; and for the golden plover *Pluvialis apricaria*, red grouse *Lagopus lagopus*, and black grouse *Tetrao tetrix*. Some forms of heath also have a significant lower plant interest, including rare and local mosses and liverworts that are particularly associated with the wetter western heaths. The invertebrate fauna is especially diverse.

Upland heathland is found throughout the uplands of England, along the Pennine Chain, the Lake District, Yorkshire Dales, Peak District, Bowland Fells, Northumberland, North York Moors, and on Exmoor, Dartmoor and Bodmin moor in the south west. There is an estimated 226,609 ha of upland heath in England.

Potential climate change impacts

Cause	Consequence	Potential impacts
Increased mean temperatures	Longer growing season (Burt & Holden 2010)	■ Increased growth of grasses and other heath species and a gradual change towards a lowland heathland structure (Carey 2013). ■ Temperature is often a limiting factor for insect and microbial performance. Warmer temperatures are likely to result in increased herbivory and faster nutrient cycling, leading to changes in vegetation.
Hotter summers	Potential for increased visitor numbers Increased likelihood of wildfires	■ An increase in unmanaged access could lead to more erosion on access routes, an increased likelihood of wildfires (Albertson *et al* 2010), and increased disturbance of ground nesting birds (e.g. Underhill-Day 2005). ■ Changes to community composition and increased erosion and loss of peat.
Warmer winters		■ Increased threat from pest species such as heather beetle.
Drier summers	Drought	■ Altered community composition. ■ Increased susceptibility to wildfire, and risk of resulting peat/soil damage under wild or managed burns. ■ Increased risk from using managed burns as a management option.
	Drier ground conditions	■ Lower summer water tables could lead to a reduction in wet heath components of the heathland ecosystem. ■ Marginal land could become suitable for more intensive agriculture.
Wetter winters	Increased surface runoff	■ Spring burning as a management option may become increasingly difficult.
Storm events	Increased rainfall intensity	■ Greater erosion, particularly affecting footpaths.
In combination		■ Loss of suitable climate for key species (Holman *et al* 2002; Berry *et al* 2005). ■ Changed food web interactions leading to reduced habitat suitability for some bird species (Pearce-Higgins 2011). ■ Expansion of bracken into higher altitudes at the expense of heather (Fraser *et al* 2009; Pakeman *et al* 2000; Carey 2013). ■ Increased productivity leading to an intensification of grazing and increased nutrient loading (Wessel *et al* 2004; Carey 2013).

Adaptation responses

Different aspects of climate change will interact and have different impacts on the various components of heathland systems. Management of existing sites will need to be flexible, and be adjusted to reflect these changes.

Heathland is threatened by many pressures that are not related to climate change, such as habitat loss and an associated increase in fragmentation and isolation, heavy access and recreation pressure, over grazing, and inappropriate or lack of management. Increasing the resilience of upland heath by reducing these pressures is likely to be a key adaptive response in many cases.

In addition to actions on existing areas of heathland, adaptation will also require targeted habitat restoration and creation to address historic habitat loss and to improve the resilience of heathland networks.

Some of the potential adaptation options for this habitat are outlined below.

- Develop fire contingency plans across the whole upland habitat mosaic and ensure that the design and management of habitats reduces fire risk, such as by introducing firebreaks and fire ponds, and restricting access to some areas at times of high fire risk. Rewetting drier, degraded blanket bog and reducing heather cover will also help to reduce fire risk.
- Minimise erosion through the management of access, grazing and burning.
- Consider allowing an increase in scrub and woodland cover within the upland mosaic to improve habitat heterogeneity, in order to provide potential refugia for sensitive plants and invertebrates.
- Within upland sites, identify areas that might act as potential refugia to climate change, such as areas with complex micro-topography, robust hydrology, and high species diversity, and ensure that these are managed accordingly.
- Maintain structural diversity within the vegetation to provide a wide range of micro habitats and niches, including, where possible, bare ground, areas dominated by mosses and lichens, low herbs, dwarf shrubs of diverse age classes, wet heath and mire, and scattered trees and shrubs.
- Consider the need to adjust designated site boundaries as habitats change (e.g. to create larger functional sites) and review the interest features for which the site is managed.
- Upland heath grades into various other habitat types along climatic gradients, particularly lowland heath with higher temperature, montane heath with lower temperature, and blanket bog in wetter conditions. Conservation objectives need to reflect these gradients, and build in an acceptance that there will change under a changing climate, and that the location for action to conserve particular species is likely to change.

Female hen harrier in flight. © Andy Hay (rspb-images.com)

Relevant Countryside Stewardship options

UP3 Management of moorland

This option aims to maintain and restore moorland priority habitats and ecosystem function, species, protect historic features and strengthen landscape character.

UP4 Management of moorland vegetation supplement

This option aims to implement an appropriate programme of vegetation management where significant change or reintroduction of burning or cutting is necessary to achieve high value environmental gain.

UP5 Moorland re-wetting supplement

This option aims to maintain or restore vegetation mosaics, wetland habitats and their associated wildlife, by facilitating the re-wetting of moorland peat soils.

UP6 Upland livestock exclusion supplement

This option aims to improve habitat and feature condition through complete removal of livestock for at least four months, often the winter grazing period.

Further information and advice

Natural England (2001) **Upland Management Handbook**.
The upland management handbook pools the expertise of many of the country's leading wildlife, farming and land management specialists to provide a blueprint for the practical delivery of the land management that will benefit upland wildlife.

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Tayside Local Biodiversity Action Plan - **Montane (habitats above the treeline)**.

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Risby Warren SSSI, Lincolnshire
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20. Lowland dry acid grassland

Climate Change Sensitivity: **Low**

Introduction

Lowland dry acid grassland is expected to be relatively robust to the direct threats posed by climate change, although the climate space of some of its component species is projected to change. A greater threat in the short to medium term will be climate change driven changes to the economics of grazing in relation to other land uses. This may lead to a decline in the availability of grazing animals, or increased pressure to intensify grazing systems or convert land to arable production.

Habitat Description

Lowland dry acid grassland typically occurs on nutrient-poor, generally free-draining soils with a pH ranging from 4 to 5.5, overlying acid rocks or superficial deposits such as sands and gravels, at heights below about 300m. It covers all acid grassland managed in functional enclosures. Swards in old and non-functional enclosures in the upland fringes, which are managed as free-range rough grazing in association with unenclosed tracts of upland, are excluded from the definition. It often occurs as an integral part of lowland heath landscapes, in parklands, and locally on coastal cliffs and shingle. It is normally managed as pasture.

Acid grassland is characterised by a range of plant species such as heath bedstraw *Galium saxatile*, sheep's-fescue *Festuca ovina*, common bent *Agrostis capillaris*, sheep's sorrel *Rumex acetosella*, sand sedge *Carex arenaria*, wavy hair-grass *Deschampsia flexuosa*, bristle bent *Agrostis curtisii*, and tormentil *Potentilla erecta*, with presence and abundance depending on community type and locality. Dwarf shrubs such as heather *Calluna vulgaris* and bilberry *Vaccinium myrtillus* can also occur but at low abundance.

Acid grasslands can have a high cover of bryophytes, and parched acid grassland can be rich in lichens. Parched acid grassland in particular contains a significant number of rare and scarce vascular plant species, many of which are annuals.

The bird fauna of acid grassland is very similar to that of other lowland dry grasslands, which collectively are considered to be a priority habitat for conservation action. Bird species of conservation concern which utilise acid grassland for breeding or wintering include woodlark *Lullula arborea*, stone-curlew *Burhinus oedicnemus*, nightjar *Caprimulgus europaeus*, lapwing *Vanellus vanellus*, skylark *Alauda arvensis*, chough *Pyrrhocorax pyrrhocorax*, green woodpecker *Picus viridis*, hen harrier *Circus cyaneus*, and merlin *Falco columbarius*.

Many of the invertebrates that occur in acid grassland are specialist species which do not occur in other types of grassland. The open parched acid grasslands on sandy soils in particular, can support a considerable number of ground-dwelling and burrowing invertebrates such as solitary bees and wasps. A number of rare and scarce species are associated with the habitat, some of which are included on the UK Biodiversity Action Plan list of species of conservation concern, such as the field-cricket *Gryllus campestris*.

Lowland dry acid grassland has undergone substantial decline in the 20th Century, mostly due to agricultural intensification, although locally, afforestation has been significant. Important concentrations occur in Breckland, the New Forest, Dorset, the Suffolk Sandlings, the Weald, Dungeness, the coasts of south west England, and the border hills of Shropshire. Stands remote from the upland fringe are now rare and it is estimated that less than 30,000 ha now remain in the UK.

Potential climate change impacts

Cause	Consequence	Potential impacts
Hotter summers	Longer growing season	■ Phenology may change significantly, with flowering and seed setting occurring earlier in season. ■ Community composition may shift to favour southern temperate and Mediterranean continental plant species (Preston *et al* 2002). ■ Bracken *Pteridium aquilinum* may spread and dominate some areas (Stewart *et al* 2008).
Warmer winters	Fewer frost days	■ Milder winters may reduce frost heaving, which will reduce the amount of bare ground for the regeneration/recruitment of annual plants from the seed bank.
Drier summers	Drought Wildfire	■ Drier conditions will favour stress-tolerant (e.g. deep rooted) and ruderal species due to the increased gaps/bare ground in swards. However, species which are intermediate between stress tolerant and competitive will be retarded by drier summers. ■ Summer drought may favour annual species over perennials, leading to community change. ■ Oceanic/sub-oceanic[8] species such as bird's-foot *Ornithopus perpusillus*, heath bedstraw *Galium saxatile* and sand spurrey *Spergularia rubra* may decline. ■ Drier summers may favour the spread of dry heath into acid grassland (Berry *et al* 2007). ■ Increased incidence of fire, especially in sites that form part of a mosaic with heathland or bracken, could lead to changes in community composition, bare ground, and increased vulnerability to invasive species.

Adaptation responses

The direct impacts of climate change may be less important than changes in land management, including the ongoing impacts of fragmentation and agricultural intensification, and the impact of atmospheric nitrogen deposition. Adaptation is therefore likely to focus on increasing the resilience of grassland by ensuring that other sources of harm are minimised. However, an adaptive approach is needed to deal with issues like changing seasonal patterns in growth and flowering.

Expanding the area of the habitat through targeted habitat restoration and creation will also be a key adaptive response, with the priority given to measures to increase the size, heterogeneity and connectivity of existing patches.

Some of the potential adaptation options for this habitat are outlined below.

- Ensure best practice management of existing stands by maintaining suitable grazing regimes and avoiding over or under-grazing, or agrochemical and fertilizer inputs.
- Ensure remaining sites are protected and buffered from agricultural intensification.

8 These are species that are restricted to the Atlantic zone (Oceanic) or sub-oceanic species that also extend beyond the Atlantic zone into the western Mediterranean and western central Europe.

- Increase the flexibility in site management to respond to the increased variance in seasonal growing conditions. For example, increase the capacity for changing the timing and intensity of grazing through the use of layback land or housing for animals when ground conditions prevent on-site grazing.
- Adjust grazing dates to align with longer term climate driven changes to flowering dates.
- Increase the area of dry acid grassland by restoring semi-improved grasslands and re-creating habitat on improved grassland and arable land to ensure the expansion and buffering of existing sites and improve the coherence of existing networks. Consideration should be given to increasing topographic and hydrological heterogeneity when identifying potential sites.
- Within sites, identify areas that might act as potential refugia from climate change, such as areas with north facing slopes, complex micro-topography, low nitrogen levels and high species diversity, and ensure that these are under optimal management.
- Permit the growth of scattered scrub, especially on drought prone sites, as this can provide a wider range of microclimates and soil conditions.
- Monitor and control the spread of potential native and non-native invasive species.
- Some changes in species complements on sites may be inevitable or even desirable (for example, an otherwise threatened species colonising a new site). Site objectives and management should be flexible enough to recognise this.

Nightjar. © Natural England/Peter Wakely

Relevant Countryside Stewardship options

GS6 Management of species-rich grassland

This option is targeted at maintain and protecting of areas of species-rich grassland.

GS7 Restoration towards species-rich grassland

This option is targeted at maintaining and protecting of areas of species-rich grassland. These are often on difficult ground and may have suffered from management neglect or may have been selected for agricultural improvement. The botanical diversity of such grassland may be enhanced by simply amending existing management practices. However, on many sites pro-active restoration management will be required, involving the introduction of seeds and the creation of gaps for their establishment. Substantial changes of livestock type, timing of grazing, or control of dominant species may also be required. This option can also contribute to protecting valued landscapes and archaeology, and the promotion of good soil conditions.

GS8 Creation of species-rich grassland

This option is aimed at creating species-rich grassland on former arable land, ley grassland or set-aside land.

Supplementary options

SP6 Cattle grazing supplement

This supplement promotes grazing by cattle where this is likely to be beneficial in meeting environmental objectives.

Further information and advice

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Relevant case study examples

Creation of lowland dry acid grassland at Minsmere, Suffolk.
Sheep grazing was introduced on former arable land at Minsmere RSPB Reserve in Suffolk, with the objective of creating acid grassland. Seven years after the introduction of a grazing regime, the grassland was well established but was still some way off approaching the cover and species richness of existing semi-natural acid grassland.

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Chalk downland with common spotted orchid and rough hawkbit, Hampshire.
© Natural England/Chris Gomersall

21. Lowland calcareous grassland

Climate Change Sensitivity: **Low**

Introduction

Unimproved calcareous grassland has been shown to be relatively resistant to climate change (Duckworth, Bunce & Malloch 2000; Grime *et al* 2008), and older grasslands are more resilient than those in earlier stages of succession (Grime *et al* 2000, Carey 2013). Climate envelope modelling indicates that there could be a potential increase in the climate space of many calcareous grassland species in the UK, although their spread would be limited by the suitability of suitable substrate (Harrison *et al* 2006).

Changes in the management of calcareous grassland will probably continue to have a greater impact on lowland calcareous grassland than the direct impacts of climate change.

Habitat Description

Lowland calcareous grassland is found on shallow, well-drained soils which are rich in bases (principally calcium carbonate) formed by the weathering of chalk and other types of limestone or base-rich rock or drift, and is characterised by vegetation dominated by grasses and herbs. Lowland is defined as below the level of agricultural enclosure. The altitude at which this occurs varies across the UK, but typically becomes higher towards the south.

Lowland calcareous grasslands support a very rich flora, including many nationally rare and scarce species such as monkey orchid *Orchis simia*, hoary rockrose *Helianthemum canum*, and pasque flower *Pulsatilla vulgaris*. The invertebrate fauna is also diverse and includes scarce species like the adonis blue butterfly *Lysandra bellargus*, the silver-spotted skipper *Hesperia comma*, the Duke of Burgundy fritillary *Hamaeris lucina*, and the wart-biter cricket *Decticus verrucivorus*. These grasslands also provide feeding or breeding habitat for a number of scarce or declining birds, including stone curlew *Burhinus oedicnemus* and skylark *Alauda arvensis*.

Lowland calcareous grasslands are characterised by lime-loving plants and are found largely in the south and east of the UK, but also in the Derbyshire White Peak, Yorkshire Wolds, Morecambe Bay and eastern County Durham, where they occur on shallow, calcareous soils generally overlying limestone rocks and drift, including chalk. These grasslands are now found largely on distinct topographic features such as escarpments or dry valley slopes that have not been improved for agriculture, but occasionally remnants survive on flatter topography such as on Salisbury Plain or in Breckland. The total area of lowland calcareous grassland in England is 38,687 ha.

Potential climate change impacts

Cause	Consequence	Potential impacts
Drier summers	Drought Wildfire	■ Changed community composition due to: ■ losses of perennials due to die back, especially in drought prone areas of the south-east (Rodwell *et al* 2007); ■ expansion of drought tolerant ephemerals and re-colonisation by annuals with a persistent seed bank (Rodwell *et al* 2007); ■ reduced growth of upright brome *Bromopsis erecta*; ■ increasing dominance and possible range expansion of heath false brome *Brachypodium pinnatum*. ■ Continued northward expansion of *Bromopsis erecta* and *Brachypodium pinnatum*, although the rate may be limited by self-incompatibility in these species (Moser & Thompson, 2014). ■ Plants with underground storage organs may have a greater ability to survive droughts, as may deep rooted species. Shallow rooted species will be disadvantaged (Sternberg *et al* 1999). ■ A decline in the abundance and diversity of associated fungi communities and specialist mosses. ■ Damage to lower plant assemblages.
Wetter winters		■ Wetter conditions could lead to an increased dominance of grasses in the sward, due to increased competition, and a reduction in broad-leaved herbaceous species that characterise calcareous grasslands.
In combination		■ Changes to farm economics driven by climate change could put existing grazing regimes at risk. ■ Possible loss or reduction in populations of species of more northern upland floristic elements (boreal montane, boreo- temperate) from northern limestone formations, e.g. limestone bedstraw *Galium sterneri*, dark red helleborine *Epipactis atrorubens* and the moss *Tortella tortuosa*. ■ A combination of increased temperature and increased nutrients from nitrogen deposition could result in a higher proportion of grasses and fewer broadleaved species, especially where drought is not expected (Carey 2013). Indeed Fridley *et al* (2016) have demonstrated that climate change mediated extension of the growing season favours more competitive, resource acquisitive species even in systems thought to be nutrient limited. This may result in competitive exclusion of slower growing species.

Adaptation responses

Lowland calcareous grassland has been shown to be relatively robust to the direct threats posed by climate change, at least in the short term, with other non-climate change drivers such as fragmentation, under or over-grazing and nutrient enrichment from atmospheric nitrogen deposition representing greater threats. In the medium term, climate change could alter the economics of grazing in relation to other land use. This may lead to a decline in the availability of grazing, an intensification of grazing systems, or pressure to convert land to arable production.

Adaptation should therefore focus on ensuring other sources of harm are reduced, to increase resilience. Priority should be given to measures to increase the size, heterogeneity and connectivity of existing patches of calcareous grassland, and these changes should be factored into long-term site management objectives.

Some of the potential adaptation options for this habitat are outlined below.

- Ensure best practice management of existing stands through suitable grazing regimes (avoiding over or under grazing), and avoiding agrochemical and fertiliser inputs.
- Increase the area of existing habitat through targeted re-creation and restoration effort around existing patches. Consideration should be given to increasing topographic, soil and hydrological heterogeneity when identifying potential sites.
- Manage the grazing of sites flexibly in response to seasonal variations in vegetation growth.
- Accept changes to community composition where we can be sure that these are driven by climate change. For example, allow the transition from upright brome *Bromposis erecta* to heath false brome *Brachypodium pinnatum* on sites where this species appears to be increasing due to climatic factors. In northern calcareous grasslands, where *B. erecta* and *B. pinnatum* are absent or at very low frequency, consider early intervention to help prevent further ingress and potential dominance of these competitive grasses.
- A certain level of scrub can be beneficial, especially on sites that are prone to heat stress or drought, due to its shading effect potentially providing micro-refugia for a suite of invertebrates.
- Within sites, identify areas that might act as potential refugia from climate change, such as areas with north facing slopes, complex micro-topography, low nitrogen levels, and high species diversity, and ensure that these are under optimal management.

Adonis blue *Lysandra bellargus*. © Natural England/Peter Wakely

Relevant Countryside Stewardship options

GS6 Management of species-rich grassland

This option is targeted at the maintenance and protection of areas of species-rich grassland.

GS7 Restoration towards species-rich grassland

This option is targeted at grasslands that are potentially rich in plant and associated animal life. They are often on difficult ground and may have suffered from management neglect or been selected for agricultural improvement. The botanical diversity of such grassland may be enhanced by simply amending existing management practices. However, on many sites pro-active restoration management will be required, involving the introduction of seeds and the creation of gaps for their establishment. Substantial changes of livestock type, timing of grazing, or control of dominant species may also be required. The option can also contribute to protecting valued landscapes and archaeology, and the promotion of good soil conditions.

GS8 Creation of species-rich grassland

This option is aimed at creating species-rich grassland on former arable land, ley grassland or set-aside land.

Supplementary options

SP6 Cattle grazing supplement

This supplement promotes grazing by cattle where this is likely to be beneficial in meeting environmental objectives.

Further information and advice

JNCC (2008) UK BAP habitat description **Lowland Calcareous Grassland**.

English Nature. Monitoring the condition of lowland grassland SSSIs: **Pt 1 English Nature's rapid assessment method (ENRR315)**.

Natural England (2008) **State of the Natural Environment**. This provides an overview of the state of England's grasslands – their extent, trends, key drivers of change, and actions to achieve favourable condition of the resource.

Relevant case study examples

Wiltshire Chalk Country Futurescapes
The Wiltshire Chalk Country project aims to re-create the largest network of chalk grassland sites in north-west Europe, connecting Salisbury Plain, Porton Down and the Stonehenge World Heritage Site, redressing historic losses and re-establishing links between remnant fragments. The RSPB is working with farmers and landowners to create new chalk grassland under Natural England's Environmental Stewardship scheme.

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Kempley Daffodil Meadow SSSI, Gloucestershire.
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22. Lowland meadow

Climate Change Sensitivity: **Medium**

Introduction

The character of lowland meadows, particularly the wetter types, is influenced by the availability of water and the seasonal variation in the water table. They will therefore be sensitive to changes in the seasonal pattern of rainfall and the interacting effects of increased summer temperature on water usage. Reductions in summer rainfall and increased summer evaporation will put stress on wet meadow communities in late summer and autumn, and rain fed systems will be more affected than those dominated by river inflows (Acreman 2009).

As lowland meadows are actively managed, climate change driven changes to the economics of livestock grazing systems may also have a significant impact.

Habitat Description

Lowland neutral meadows and pastures consist of a rich mixture of native grasses and broad-leaved herbs. They occur throughout lowland UK, often on shallow slopes or level ground with relatively deep soils that are neither strongly acidic nor lime-rich. The meadows may be managed for hay cropping, usually with grazing of the aftermath (vegetation that re-grows following cutting), or by grazing as permanent pasture.

Up to 35 or more plant species may occur in a 2mx2m sample, including grasses such as crested dog's-tail *Cynosurus cristatus* and red fescue *Festuca rubra*, and herbs such as knapweed *Centaurea nigra*, bird's-foot trefoil *Lotus corniculatus* and ox-eye daisy *Leucanthemum vulgare*. Some pastures may be important for waxcap and earth-tongue fungi. Old meadows and pastures can support a rich insect community, including butterflies, grasshoppers, bumblebees and yellow meadow ants. They can also provide important feeding areas for birds such as the linnet *Carduelis cannabina* and meadow pipit *Anthus pratensis*, and bats and small mammals such as the field vole *Microtus agrestis*.

The flora of lowland meadows can include rare and scarce species such as snakes's head fritillary *Fritillaria meleagris*, sulphur clover *Trifolium ochroleucon*, field gentian *Gentianella campestris*, and green-winged orchid *Orchis morio*. This may be matched by a scarce invertebrate fauna, including hornet robber-fly *Asilus crabroniformis* and shrill carder bee *Bombus silvarum*.

Lowland meadows include the now scarce flood-meadows of central England and eastern Wales, which rely on seasonal flooding in winter, and support tall, moisture-loving species such as great burnet *Sanguisorba officinalis*, meadowsweet *Filipendula ulmaria*, and pepper-saxifrage *Silaum silaus*.

Lowland grassland habitats and their associated species face a number of pressures and threats, which conservation initiatives are trying to address. Most grassland in the UK has undergone agricultural improvement through ploughing and re-sowing, heavy inputs of fertilisers, and intensive cutting or grazing. This remains an important threat, as does over-grazing or cutting at the wrong time of year. Increasingly, grasslands are also threatened by under-management or abandonment of traditional grazing or cutting.

The overall result of habitat change in the lowland agricultural zone is that *Cynosurus - Centaurea* grassland, the mainstream community of unimproved hay meadows and pastures over much of Britain, is now highly localised, fragmented and in small stands.

There is an especially important concentration in Worcestershire, and other particularly important areas include south-west England (Somerset, Dorset and Wiltshire), and in the East Midlands and East Anglia (Leicestershire, Northamptonshire, Cambridgeshire and Suffolk).

Unimproved seasonally-flooded grasslands are less widely distributed. They have lower overall cover, but there are still a few quite large stands. *Alopecurus - Sanguisorba* flood-meadow has a total cover of less than 1500 ha and is found in scattered sites from the Thames valley through the Midlands and Welsh borders to the Ouse catchment in Yorkshire. These include well known but now very rare Lammas meadows, such as North Meadow, Cricklade, and Pixey and Yarnton Meads near Oxford, which are shut up for hay in early spring, cropped in July, with aftermath grazing from early August; and where nutrients are supplied by flooding episodes in winter. *Cynosurus - Caltha* flood-pasture is also now scarce and localised, with less than 1000 ha in England. In total, there are an estimated 7,245ha of lowland meadow in England.

Snake's head fritillary. North Meadow, Cricklade NNR. © Natural England/Peter Wakely

Potential climate change impacts

Cause	Consequence	Potential impacts
Hotter summers	Longer growing season	■ Phenology may change significantly, with flowering and seed setting occurring earlier in season.
Drier summers	Drought	■ Drier conditions will favour stress-tolerant (e.g. deep-rooted) and ruderal species due to the increased gaps/bare ground in swards. However, species which are intermediate between stress tolerant and competitive will be retarded by drier summers. ■ Changes in species communities and composition, including possible movement from MG4 and MG8 vegetation types to MG5 (Carey 2013). ■ On wetter lowland meadows, increased abstraction during warmer weather, leading to reduced water tables and water availability, may result in a shift in the botanical composition to species associated with drier conditions, and a decline in the wetland species component. ■ Drier conditions could favour a switch from silage production to hay making, which would generally bring biodiversity benefits.
Wetter winters	Winter flooding Higher winter water table	■ More frequent inundation of wetter sites may lead to changes in floodplain wetlands as the component plants of the community are more prone to increasing wetness than to summer drought (Toogood, Joyce & Waite 2008). ■ Higher spring soil moisture levels, combined with higher spring temperatures, may increase total biomass and favour more competitive species. ■ Any increase in hard flood defences could lead to changes in the hydrology of sites. ■ Longer flooding events may lead to increased phosphorus levels in floodplain soils, with the potential for altering plant community composition. ■ MG4 flood plain meadows are particularly vulnerable to larger and longer flooding events, in particular those that occur outside of the autumn/winter period. Such events will cause adverse vegetation change towards less highly valued types such as swamp and inundation grassland.
Altered seasonal rainfall patterns	Altered flow regimes Increased fluctuation in water tables (Thompson *et al* 2009)	■ On wetter sites, specialist wetland plant species may be outcompeted by more generalist species adapted to drier and or fluctuating conditions, leading to changes in community composition (Toogood, Joyce & Waite 2008). Floodplain wetlands that are dependent on marked flow peaks and troughs are especially sensitive. ■ Increased disturbance could increase susceptibility to the spread of invasive species (Stromberg *et al* 2007, Knight *et al* 2014).
More extreme events	Flooding	■ Increased summer flooding events, especially if regular and prolonged, would lead to replacement of the floodplain-meadow plant community with swamp communities, in which the species are better adapted to cope with waterlogged soil. ■ Increased deposition of phosphorous (Gowing 2008). ■ Increased pollution risk.
In combination	Changed economics of livestock grazing systems Increased pollution	■ Changes in the economics of grazing could increase pressure for the intensification of existing low input grasslands or, conversely, could lead to increased land abandonment and under-grazing. ■ Increased nitrogen loading in watercourses due to increased mineralisation at higher temperatures, combined with reduced dilution due to lower flows (Whitehead *et al* 2006). For the wetter meadows increased N input via groundwater/floodwater will favour competitive, often less desirable, plant species, at the expense of the slower growing species that often characterise high value semi-natural meadow communities.

Adaptation responses

Lowland meadows are actively managed through grazing, cutting or a combination of the two. Increased flexibility in both the date and intensity of these management options in response to both long term changes and seasonal variability in growing conditions will become increasingly important for maintaining the biodiversity interest of these habitats.

For wet grasslands, ensuring an adequate supply, temporal variation and quality of water is a key adaptation objective. In the short term, this is likely to take the form of restoring and maintaining ditch networks, but over the longer term will require planning at the catchment level to restore the capacity of catchments to hold, retain and maintain flows under both wet and dry conditions.

Successful adaptation will require both site–based and catchment scale solutions to be considered. Some of the potential adaptation options for this habitat are outlined below.

- Increase the flexibility of site management to respond to the increased variation in seasonal growing conditions. For example, vary the timing of the hay cut or the timing, duration and extent of aftermath grazing.
- Move cutting and grazing dates to align with climate driven changes to flowering dates.
- At the site level, take action to maintain or restore water level management, including actions to increase the water holding capacity of sites such as restoring ditch networks and reviewing the use of water management structures.
- Monitor and ensure the control of potential invasive species. Actions could include introducing biosecurity measures to minimise colonisation by invasive non-native species and increasing surveillance to identify the presence of any invasive non-native species before they become too widespread.
- Expand the area of lowland meadows by restoring semi-improved grasslands and re-creating lowland meadows on improved grassland and arable land. Where possible, action should be targeted at expanding and linking existing sites.
- Increase the structural heterogeneity of meadows in larger sites through varying the type and timing of management interventions.

Relevant Countryside Stewardship options

GS6 Management of species-rich grassland

This option is targeted at the maintenance and protection of areas of species-rich grassland.

GS7 Restoration towards species-rich grassland

This option is targeted at grasslands that are potentially rich in plant and associated animal life. They are often on difficult ground and may have suffered from management neglect or been the subject of agricultural improvement. The botanical diversity of such grassland may be enhanced by simply amending existing management practices. However, on many sites pro-active restoration management will be required involving the introduction of seeds and the creation of gaps for their establishment. Substantial changes of livestock type, timing of grazing or control of dominant species may also be required. The option can also contribute to protecting valued landscapes and archaeology, and the promotion of good soil conditions.

GS8 Creation of species-rich grassland

This option is aimed at creating species-rich grassland on former arable land, ley grassland or set-aside.

Supplementary options

GS15 Haymaking supplement

This option aims to ensure the continuation or re-introduction of hay-making on sites where the ready availability of livestock and/or the climatic difficulty of haymaking means they would otherwise be grazed and not cut. Sites will have high existing or potential value as meadow land. It will also help ensure hay-making techniques and traditions are not lost to future generations.

GS16 Rush infestation control supplement

This supplement is aimed at reducing rush cover in parcels with heavy infestations to help prevent loss of botanically-rich wet grasslands and/or provide nesting areas benefit breeding wading birds.

SP2 Raised water levels

This supplement is aimed at raising water levels in ditches, and thus adjacent land, at key periods of the year. It will enhance the grassland habitat for wetland plants, as well as the diversity of fauna and flora of the ditches, and may, in the right situation, provide an area of flood storage.

SP6 Cattle grazing supplement

This supplement promotes grazing by cattle where this is likely to be beneficial in meeting environmental objectives.

Further information and advice

JNCC (2008) UK BAP habitat description **Lowland Meadow**.

Rodwell JS, Morgan V, Jefferson RG & Moss D. (2007) **The European context of British Lowland Grasslands** JNCC Report, No. 394.

Natural England (2008) **State of the Natural Environment**. This provides an overview of the state of England's grasslands – their extent, trends, key drivers of change, and actions to achieve favourable condition of the resource.

English Nature. Monitoring the condition of lowland grassland SSSIs **Pt 1 English Nature's rapid assessment method (ENRR315)**.

Natural England Technical Information Note **National Vegetation Classification: MG5**. (TIN 147)

The Floodplain Meadow Partnership. Useful information about floodplain meadows and their management.

Relevant case study examples

Floodplain Meadows Partnership Restoration Case Study – Broadmeadow and Middle Park
The aim of this project was to re-create areas of species-rich grassland using the Environmental Stewardship Higher Level Scheme (HLS). The first meadows were re-created in 2008, with others re- created during the autumn and spring of 2010-11.

Monmouthshire Meadows Group
The aim of this group is to conserve and restore flower rich grasslands in Monmouthshire by enabling members to manage their own fields and gardens effectively.

Key evidence documents

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Grazing marshes and dyke, Halvergate Marshes SSSI, Norfolk.
© Natural England/Peter Wakely

23. Coastal floodplain and grazing marsh

Climate Change Sensitivity: **Medium**

Introduction

Coastal and floodplain grazing marsh is dependent on periodic inundation and high water levels, which means that it is sensitive to the projected changes in patterns of rainfall and extreme events such as drought and flooding. Coastal grazing marsh is at additional risk from sea level rise, leading to increased inundation, potential coastal erosion, and coastal squeeze, with freshwater sites adjacent to the coast sensitive to saline intrusion. Coastal grazing marsh is also vulnerable to human responses to sea level rise, including losing space to intertidal habitats following managed realignment schemes.

As coastal and floodplain grazing marshes are maintained by grazing, climate change driven changes to the economics of grazing systems may also have a significant impact.

Habitat Description

Coastal and floodplain grazing marsh is not a specific habitat but a landscape type which supports a variety of habitats; the defining features being hydrological and topographical rather than botanical. Grazing marsh is defined as periodically inundated pasture or meadow, typically with ditches or rills containing standing brackish or fresh water. The majority of sites have low botanical grassland interest, but nevertheless support bird species of high conservation value, while the ditches can be especially rich in plants and invertebrates.

Almost all areas are grazed, and some are cut for hay or silage. Sites may contain seasonal water- filled hollows and permanent ponds with emergent swamp communities, but not extensive areas of tall fen species like reeds, although they form part of the mosaic of river valley habitats and may abut fen and reed swamp communities. The habitat is characterised by the control of water levels through the use of pumps and/or sluices.

Grazing marshes are particularly important for the number of breeding waders they support, such as snipe *Gallinago gallinago*, lapwing *Vanellus vanellus*, redshank *Tringa totanus*, and curlew *Numenius arquata*. Internationally important populations of wintering wildfowl also occur, including Bewick's swans *Cygnus columbianus bewickii* and whooper swans *Cygnus cygnus*.

Grazing marsh grasslands are typically dominated by the more common grasses of neutral soils, for example meadow foxtail *Alopecurus pratensis*, crested dog's tail *Cynosuarus cristatus*, rye grass *Lolium perenne*, and Yorkshire fog *Holcus lanatus*; while on coastal marshes, red fescue *Festuca rubra* and creeping bent *Agrostis stolonifera* grassland are frequently found.

Ditches have a wide variety of plant species, with the principal environmental variables influencing vegetation being salinity, water depth, substrate and successional stage. Characteristic species range from common reed *Phragmites australis*, along with species more typically associated with freshwater swamps and fens, such as greater pond-sedge *Carex riparia* and reed sweet-grass *Glyceria maxima*; duckweed *Lemna spp.*, flote-grass *Glyceria fluitans* and frogbit *Hydrocharis morsus-ranae* dominated communities; and sea club-rush *Bolboschoenus maritimus*.

The dominant freshwater and brackish aquatic macro-invertebrates of drainage ditches include beetles, bugs, snails, and fly larva. The ornate brigadier soldierfly *Odontomyia ornata* and the great silver diving beetle *Hydrophilus piceus* have been recently described as 'flagship species' for grazing marshes. Grazing marshes are also important habitats for dragonflies. For example, 14 species out of a British total of 44 occur on the Essex marshes.

There are an estimated 220,000 ha of coastal and floodplain grazing marsh in England. However, only approximately 5,000 ha of this grassland is semi-natural and supports a high diversity of native plant species.

Potential climate change impacts

Cause	Consequence	Potential impacts
Hotter summers	Longer growing season	■ Phenology may change significantly, with flowering and seed setting occurring earlier in the season. ■ The earlier onset of the growing season may lead to less favourable conditions for ground nesting birds such as lapwing that require a short sward.
Drier summers	Drought	■ Drier conditions will favour stress tolerant (e.g. deep-rooted) and ruderal species. ■ Food availability for ground nesting birds in late spring and summer could be reduced. ■ In peat rich areas, dryer conditions could cause damage to soil structure and increase erosion. ■ Any increase in water abstraction could lower water tables and reduce water availability, and potentially lead to increased saline intrusion on coastal sites.
Wetter winters	Winter flooding Higher winter water table	■ Changes to inundation patterns on wetter sites could lead to changes in floodplain wetland plant communities and affect suitability for over-wintering water birds. ■ Higher spring soil moisture levels (combined with higher spring temperatures) may boost total biomass and favour more competitive species. ■ Wetter ground conditions may create difficulties for grazing.
Altered seasonal rainfall patterns	Altered flow regimes Greater fluctuation of water tables	■ Plant communities on wetter sites may change as specialist wetland species are outcompeted by more generalist species adapted to drier and/or fluctuating conditions (Toogood, Joyce & Waite 2008). Floodplain wetlands dependent on marked flow peak and snow melt are especially sensitive. ■ Increased disturbance could increase susceptibility to the spread of invasive species.
More extreme events	Flooding	■ More frequent flooding will increase the risk of pollution run-off. ■ Flooding of brackish water bodies and sites with fresh water could lead to the loss of specialist species. ■ Unseasonal summer flooding could affect the breeding success of waders.
Sea Level Rise	Altered coastal dynamics Saline Intrusion Increased frequency of saline inundation Managed realignment, or unmanaged realignment following the abandonment of coastal defence structures	■ Sea level rise could result in the loss of intertidal habitats, increasing the threat of inundation and erosion of adjacent grazing marsh. ■ Saline intrusion will lead to a change in community structure on freshwater sites close to the coast and estuaries, with a shift from freshwater to brackish communities. ■ More frequent inundation could increase the area of exposed mud, making marshes more susceptible to invasive plants and erosion. ■ Coastal realignment could lead to the loss of both coastal and floodplain grazing marsh (Gardiner *et al* 2007), in favour of intertidal and salt marsh habitats.
In combination	Increased pollution and nutrient loading	■ Increased mineralisation at higher temperatures, combined with reduced dilution due to lower flows, could lead to increase nitrogen loading in water courses, which could contribute to the eutrophication of ditch networks and watercourses (Mooij *et al* 2005; Moss *et al* 2011).

Adaptation responses

Coastal grazing marsh is a habitat created by drainage and the creation of flood defences, as it occupies former intertidal zones. On-site adaptation of these coastal sites is therefore likely to involve the active management of flood defence and drainage systems, combined with off-site planning, including managed realignment, that will need to take into account the full suite of coastal habitats. Actions to promote adaptation should be integrated with the existing shoreline management planning process.

For inland floodplain grazing marsh, actions that ensure the continued supply of water and control over water levels are likely to be the primary objectives of adaptation.

Some of the potential adaptation options for this habitat are outlined below.

- Take action to ensure non-climatic sources of harm are reduced, such as reducing the risk of pollution, minimising the adverse impacts of drainage and abstraction, and managing visitor numbers.
- Plan and take action to achieve desirable water levels on site. This might include measures to reduce water loss, providing additional storage for water abstracted from rivers in winter when flows are high, securing additional supplies of water, and increasing the ability to move water around on site.
- Minimise over and under-grazing through flexible management, for example by adjusting stocking density and the timing of grazing regimes in response to seasonal variations in growing conditions. This may require an increase in layback land – land use to graze livestock when they are not on the marsh.
- Expand the area of grazing marsh by re-introducing appropriate water level management on improved grassland and arable land. This should be targeted to ensure the expansion and linkage of existing sites and to promote functioning coastal floodplains (i.e. those that permit natural flooding regimes).
- Increase the structural heterogeneity of grazing marsh on larger sites by varying the type and timing of management interventions, including allowing areas of bare ground and isolated scrub.
- Monitor and ensure the control of potential invasive non-native species through effective biosecurity measures. Identify potential sources of invasive species in the surrounding area, and undertake active surveillance to detect the arrival of potentially invasive species at an early stage, while they can still be eradicated.
- Anticipate and develop approaches to managing the landward movement of grazing marshes by identifying potential sites for habitat creation.
- Ensure that managed realignment for flood defence or the conservation of intertidal habitat such as mud flats and salt marsh do not compromise the area or quality of coastal and fluvial grazing marsh.
- Adjust designated site boundaries and interest features as coasts evolve, with the aim of creating larger functional units.

Relevant Countryside Stewardship options

HS7 Management of historic water meadows through traditional irrigation

This options aims to maintain the demanding traditional management required on both 'bedwork' and 'catch' water meadows, and to maintain habitat and water quality.

GS9 Management of wet grassland for breeding waders

This option aims to maintain or restore wet grassland for breeding wading birds through provision of feeding habitat and a suitable sward structure for nesting.

GS10 Management of wet grassland for wintering waders and wildfowl

This option aims to provide suitable habitat for wintering wildfowl and wading birds on wet grassland.

GS11 Creation of wet grassland for breeding waders

This option aims to create wet grassland for breeding wading birds from arable or temporary grassland.

GS12 Creation of wet grassland for wintering waders and wildfowl

This option aims to create wet grassland for wintering waders and wildfowl, from arable or temporary grassland.

SP2 Raised water level supplement

This option aims to raise and maintain water levels in ditches and adjacent land, where exceptional and time-consuming management is needed at key times of the year.

WT3 Management of ditches of high environmental value

This option aims to sensitively manage ditches of high environmental value that support target species of plants, birds, mammals and insects, or are essential to the delivery of the wet grassland and wetland options.

WN3 Ditch, dyke and rhine restoration

This option aims to restore the wildlife value of over-grown or neglected ditches and/or to help establish raised water levels for habitat restoration or creation.

Further information and advice

JNCC (2008) UK BAP list of priority habitats **Coastal and Floodplain Grazing Marsh**.

Rodwell, J.S., Morgan, V., Jefferson, R.G., & Moss, D. (2007). JNCC Report, No. 394. **The European context of British Lowland Grasslands**.

Buglife. Advice Sheet **Coastal and Floodplain Grazing Marsh**.

Environment Agency **Shoreline Management Plans (SMPs)**. Information about Shoreline Management Plans, which aim to manage the risks of flooding and coastal erosion, using a whole coast approach.

Wetland Vision A partnership project which sets out a 50 year vision to improve the quality, distribution and functionality of England's wetlands.

Relevant case study examples

Lincolnshire Coastal Grazing Marshes
The Lincolnshire Coastal Grazing Marshes lie between the coastal strip and the Lincolnshire Wolds. The project supports local farmers and landowners to conserve the remaining traditional grazing marsh by providing access to grants, advice and training.

Cattle grazing, Cabin Hill NNR, Merseyside. © Natural England/Peter Wakely

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Upland hay meadow, Wensleydale.
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24. Upland hay meadow

Climate Change Sensitivity: **Medium**

Introduction

Many species that make up upland hay meadows are expected to be relatively resilient to projected climate change (Berry *et al* 2005). However, key species such as wood cranesbill *Geranium sylvaticum* and melancholy thistle *Cirsium heterophyllum*, which belong to boreal-montane floristic elements, are likely to decline due to increased competition from lowland species (Carey 2013). upland hay meadows are also highly susceptible to changes in the economics of upland grazing systems, though around 53% is under protective SSSI designation.

Habitat Description

The habitat comprises of *Anthoxanthum odoratum - Geranium sylvaticum* grassland[9] and is characterised by a dense growth of grasses and herbaceous plants up to 60 - 80 cm high. No single grass species is consistently dominant and the most striking feature of the vegetation is generally the variety and abundance of flowering plants, including wood crane's-bill *Geranium sylvaticum*, pignut *Conopodium majus*, great burnet *Sanguisorba officinalis* and lady's mantles *Alchemilla spp.*

Most of the variation within this habitat is attributable to management treatments. The fields are grazed in winter, mainly by sheep, except in the worst weather. In late April to early May the meadows are shut up for hay. Mowing takes place in mid to late July, though in unfavourable seasons it may be delayed to as late as September. The aftermath is then grazed once more until the weather deteriorates. Traditionally, the meadows have been given a light dressing of farmyard manure in the spring, and this, together with occasional liming, may have helped maintain the distinctive floristic composition of these species-rich grasslands.

Upland hay meadows are confined to areas where non-intensive hay meadow management has been applied in a sub-montane climate. They are most characteristic of brown earth soils on level to moderately sloping sites between 200m and 400m altitude. Stands of *Anthoxanthum - Geranium* meadow are typically found in isolated fields or groups of fields, where many are still managed as hay meadows, but they are also recorded on river banks, road verges, and in woodland clearings. Most stands of the habitat are less than 2 ha in extent.

The main concentrations of upland hay meadow are in the northern Pennines of North Yorkshire, Durham and east Cumbria, but there are scattered locations in west Cumbria, Lancashire and Northumberland. The most important centres are Teesdale, Lunedale, Weardale and Baldersdale in Durham, Swaledale and Wharfedale in North Yorkshire, and around Tebay, Orton and Ravenstonedale in Cumbria. Recent estimates indicate that there are less than 1,000 ha in northern England.

9 Upland forms of MG8 *Cynosurus cristatus -Caltha palustris* grassland are now included in the Priority Habitat definition for upland hay meadow. However, this is dealt with under the lowland meadows account.

Potential climate change impacts

Typical species of these grasslands include those that are adapted to cooler climates. As the climate becomes warmer, these more boreal species will be outcompeted by those adapted to higher temperatures already present within the grassland community and over time by more southerly species which may colonise. Alongside any direct impacts, the influence of climate change on the economics of upland grazing systems may also be important, particularly in sites that are not protected.

Cause	Consequence	Potential impacts
Hotter summers Warmer winters	Longer growing season Fewer frosts	■ Phenology may change significantly, with flowering and seed-setting occurring earlier in the season. Earlier warming in spring may give competitive species, especially grasses, an advantage over slower-growing stress-tolerant species, leading to detrimental floristic change. ■ Boreal-montane species are likely to be increasingly out-competed by species with more southerly distributions as temperatures increase. ■ Southern species may start to colonise new sites. ■ Key species such as *Geranium sylvaticum* that require vernalisation may become less competitive and be lost (Rodwell *et al* 2007).
Drier summers	Drought	■ An increased frequency of drought would favour stress-tolerant and deep-rooted species. It could also potentially favour ruderal species where there are open gaps in the sward. This may lead to the decline of representative plant species such as wood cranes bill and lady's mantle (Carey 2013). It should however be noted that climate projections indicate lower summer rainfall in the north and west where these grasslands are found, though the declines are less than in the south and east. Rainfall is also higher to start with in many upland areas.
Wetter winters	Higher water tables and increased water-logging	■ Wetter conditions could reduce accessibility for management operations, which could lead to an increase in rushes *Juncus spp*, which may need controlling.
In combination	Changed economics of pastoral systems	■ Climate change could increase pressure for intensification of existing low input grasslands, or reduce their economic viability, leading to under-grazing and possible land abandonment.

Adaptation responses

Adaptation is likely to focus on increasing the resilience of grassland by minimising other sources of harm. Management of sites will need to be flexible, and adjusted to reflect changing conditions and community composition.

Important components of upland hay meadows will inevitably lose climate space, so identifying and protecting potential climate change refugia will be important. Local climatic variations can be large in upland areas and vulnerabilities of sites may vary considerably within the same geographic area. Targeted habitat creation and restoration will also be important to ensuring the resilience of upland ecological networks.

Some of the potential adaptation options for this habitat are outlined below:

- Adopt greater flexibility in the management of sites in response to increasing fluctuations in seasonal growing conditions. For example, recent evidence suggests that the impacts of grazing later into spring are more pronounced in warm (advanced) springs as plants are repeatedly arrested in their development through continual defoliation. While perennial species, including grasses, may tolerate periods of prolonged grazing into the growing season, annuals such as hay rattle *Rhinanthus minor* can suffer from high losses of germinating seedlings (Smith *et al* 2012). Over a number of years extending grazing into May resulted in reduced species diversity and a shift towards a more semi-improved grassland sward. Adaptive management may include varying the timing of the hay cut, bringing forward the date when grazing is stopped in order to grow hay, or changing the timing, duration and extent of aftermath grazing.
- Identify areas that might act as potential refugia to climate change, particularly areas with relatively cool and damp local climates, and ensure that these are properly protected and managed.
- Where possible, expand the area of upland hay meadows by restoring semi-improved grasslands and re-creating hay meadows on improved grassland and arable land. This should be targeted to ensure expansion and linkage of existing sites.
- Increase the structural heterogeneity of meadows in larger sites by varying the type and timing of management interventions.

Hay meadow prior to cutting. Gowk Bank NNR, Cumbria. © Natural England/Peter Wakely

Relevant Countryside Stewardship options

GS6 Management of species-rich grassland

This option is targeted at the maintenance and protection of areas of species-rich grassland.

GS7 Restoration towards species-rich grassland

This option is targeted at grasslands that are potentially rich in plant and associated animal life. They are often on difficult ground and may have suffered from management neglect or been selected for agricultural improvement. The botanical diversity of such grassland may be enhanced by simply amending existing management practices. However, on many sites, pro-active restoration management will be required, involving the introduction of seeds and the creation of gaps for their establishment. Substantial changes of livestock type, timing of grazing or control of dominant species may also be required. The option can also contribute to protecting valued landscapes and archaeology, and the promotion of good soil conditions.

GS8 Creation of species-rich grassland

This option is aimed at creating species-rich grassland on former arable land, ley grassland or set-aside.

Supplementary options

GS15 Haymaking supplement

This option aims to ensure the continuation or re-introduction of haymaking on sites where the ready availability of livestock and/or the climatic difficulty of haymaking means they would otherwise be grazed and not cut. Sites will have high existing or potential value as meadow land. It will also help ensure haymaking techniques and traditions are not lost to future generations.

GS16 Rush infestation control supplement

This supplement is aimed at reducing rush cover in parcels with heavy infestations to help prevent loss of botanically-rich wet grasslands and/or provide nesting areas benefit breeding wading birds.

Further information and advice

JNCC (2008) UK BAP habitat description **Upland Hay Meadows**.

The European context of British Lowland Grasslands. Rodwell, J.S., Morgan, V., Jefferson, R.G. & Moss, D. (2007). JNCC Report, No. 394.

Monitoring the condition of lowland grassland SSSIs: **Pt 1 English Nature's rapid assessment method (ENRR315)**.

Relevant case study examples

Hay Time

The Hay Time project was set up to co-ordinate restoration schemes using locally-harvested meadow seed in the Yorkshire Dales. The project aimed to restore at least 200 ha of upland and lowland meadows within and close to the Yorkshire Dales National Park.

Key evidence documents

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Hayeswater, Cumbria.
© Natural England/Peter Wakely

25. Upland acid grassland

Climate Change Sensitivity: **Low**

Introduction

The direct impacts of climate change on upland acid grassland are likely to be outweighed by its impact on how it is managed. However, the loss of habitat space for upland species, coupled with increased competition from lowland and more southerly species, is likely to lead to changes in community composition.

Habitat Description

Upland acid grassland is characterised by vegetation dominated by grasses and herbs, and is found on a range of usually lime-deficient soils which have been derived from acid rocks such as sandstones and acid igneous rocks, and on superficial deposits such as sands and gravels. Although the habitat is typically species-poor, a wide range of communities occur in the UK. Large expanses of acid grassland, uniform in character, occur in the uplands, with much of it being derived from dry heath. While these areas have a limited biodiversity interest, they contribute to the overall conservation interest of upland habitats. Upland is defined as land above the level of agricultural enclosure. This generally occurs at 250 – 300m in England, and typically becomes lower as one travels north.

Upland acid grassland is frequently the result of long-term grazing, where the previous habitats, e.g. woodland or dwarf shrub heath, has been grazed out. They are found on the open fell and on enclosed 'in-bye' land. The typical constituents of upland acid grassland are sweet vernal grass *Anthoxanthum odoratum*, mat-grass *Nardus stricta*, common wood-rush *Luzula multiflora*, heath bedstraw *Galium saxatile*, tormentil *Potentilla erecta*, and the mosses, springy turf-moss *Rhytidiadelphus squarrosus* and Broom moss *Dicranum scoparium*. The actual grassland type is defined by the dominant species.

The abundant 'white moors' of the uplands are dominated by mat-grass. The unpalatability of mat-grass means that sheep prefer to graze almost any other species present, which further reduces the nature conservation interest of the habitat.

On wetter ground, heath rush *Juncus squarrosus* is the dominant species, although hard rush *Juncus inflexus* and soft rush *Juncus effusus* are also common. This is the typical habitat of moorland edge and in-bye land. These areas of rough pasture are important feeding and nesting grounds for birds such as black grouse *Tetrao tetrix*, curlew *Numenius arquata*, snipe *Gallinago gallinago*, golden plover *Pluvialis apricaria*, redshank *Tringa totanus*, and lapwing *Vanellus vanellus*. Occasionally wavy hair-grass *Deschampsia flexuosa* is the dominant species on upland grassland sites. This is normally a result of burning or sudden cessation of grazing on dwarf shrub heath, which favours wavy hair-grass, and is only of short duration.

Potential climate change impacts

Cause	Consequence	Potential impacts
Higher average temperatures	Longer growing season	■ Phenology may change significantly, with flowering and seed setting occurring earlier in the season. Productivity may increase if not offset by other changes.
Drier summers	Drought	■ Drought can have major impacts on grasslands, but in the case of this habitat, the already wet conditions mean this is more likely to be an issue in drier areas on the southern and eastern margins of the uplands. Wetter winters will also offset some of the impacts of drier summers, particularly in early summer. Subject to these caveats, drought could potentially alter community composition by favouring deeper rooted species and ruderal species able to colonise gaps in the sward. It might also lead to changes in soil chemistry, with, for example, increased oxidation and decomposition affecting pH and fertility, with effects on species composition.
Wetter winters	Flooding	■ Increased precipitation could increase the risk of surface water run-off and erosion, leading to a reduction in raw water quality in water courses. ■ Increased flooding and water-logging could limit access for management operations.

Adaptation responses

Changing phenology and a potentially greater seasonal variation in rainfall means that flexibility in moving stock and stocking density is likely to become more important to ensure good grassland management. This is true both for good agricultural practice and to maintain conservation interests, for example to maintain vegetation structure that supports animal populations.

Some changes in the composition of plant communities may well be inevitable, but are not likely to threaten conservation objectives as the habitat type supports few threatened plant species. They will however need to be recognised when management objectives are being set.

Ongoing efforts to restore the network of upland sites remain valuable. Increasing emphasis may be placed on improving the heterogeneity of sites within the network, and on including areas likely to be buffered from the impacts of climate change.

Some of the potential adaptation options for this habitat are outlined below.

- Increase the flexibility in site management to respond to the increasing variance in seasonal growing conditions, particularly in the timing or duration of grazing.
- Identify areas that are likely to be buffered from the impacts of climate change and have the potential to be refugia, for example north facing slopes and areas with access to permanent sources of water, and ensure these areas are fully protected.
- Increase the structural heterogeneity of larger sites through varying the type and timing of management interventions.
- Build in changing community composition to designation criteria and site evaluation.

- Acid grassland occurs naturally as part of the mosaic of habitats found above the moorland wall, but grazing practices of the past 40 years in particular have seen the area of this habitat increase following the removal of heather by over-grazing. In some areas, the restoration of heather may be desirable for landscape or grouse management purposes. Where this is the case, the initial action will be to review the timing and extent of grazing. In some instances, further intervention will be required.
- An alternative to the restoration of heather on acid grassland sites would be to introduce or increase the area of trees, scrub and woodland. Gills and edges of water courses are the obvious places to commence this type of restoration, which could also be carried out in tandem with heather restoration. Proposals for increasing tree cover away from gills should include an assessment of likely impact upon other nature conservation interest, especially birds or habitats of international importance.

Relevant Countryside Stewardship options

UP1 Enclosed rough grazing

This option should be used to maintain and enhance areas of enclosed rough grazing land that contain extensive areas of moorland vegetation but do not meet moorland priority habitat status over the majority of the parcel.

UP2 Management of rough grazing for birds

This option should be used to restore and/or maintain populations of upland birds, normally breeding waders such as lapwing, snipe, redshank, curlew and golden plover, but may also include yellow wagtail, black grouse or other priority species, by appropriate water level management and providing the grassland habitat and sward structure suitable for feeding and nesting.

UP3 Management of moorland

This option should be used to maintain and restore moorland priority habitats and ecosystem functions, protect species, strengthen landscape character, and protect historic features.

GS6 Maintenance of species-rich grassland

This option is targeted at the maintenance and protection of areas of species-rich grassland. It should only be used on botanically diverse upland acid grassland which meets the option eligibility criteria.

Further information and advice

Plantlife Guide to grassland habitats.

Gwent Wildlife Trust, Land Management Toolkit No. 3 **Acid Grassland**.

Key evidence documents

Natural England (2013) **Review of Upland Evidence**. This wide ranging review looked at the evidence relating to biodiversity and ecosystem services in the uplands and the impact of land management activities. The report on moorland grazing and stocking rates is particularly relevant to upland acid grassland.

Curlew *Numenius arquata*. © Natural England/Allan Drewitt

Scafell from Coniston Old Man. Lake District, Cumbria.
© Natural England/Andrew Mackintosh

26. Montane habitats

Climate Change Vulnerability: **High**

Introduction

These are a group of habitats with a restricted range, determined largely by low temperatures. They include a number of arctic-alpine plant species which are adapted to low temperatures and short growing seasons, and many are at the southern limits of their world distribution in Britain. As temperatures increase, community composition will change, with more widespread upland plants starting to out-compete those particularly adapted to cold conditions (e.g. Britton *et al* 2009).

Much of this habitat in England is in poor condition due to past over-grazing by sheep. Although grazing pressure has been reduced in many areas in recent years, environmental conditions at these altitudes mean that recovery can be slow. Mountains are already popular for public access, and any climate change related increase in visitor numbers could exacerbate existing problems of trampling and erosion along access routes.

Habitat Description

Montane habitats consist of a range of near-natural vegetation which lies above the natural tree-line. In England, this is generally found above 600m, although the precise altitude varies across the country depending on local variations in temperature, shelter and humidity (Natural England 2001).

The montane zone consists mainly of high plateaus with steep-sided corries, rocky cliffs, peaks, boulder fields and scree slopes. The vegetation is influenced by factors such as rainfall, geology, aspect, soil type and depth, exposure, and extent of snow cover.

Montane habitats are generally regarded as climax communities. The vegetation within these habitats includes dwarf-shrub heaths, grass-heaths, dwarf-herb communities, willow scrub, and snowbed communities. The most abundant vegetation types are heaths dominated by heather *Calluna vulgaris* and billbery *Vaccinium myrtillus*, typically with abundant bryophytes (e.g. woolly fringe-moss *Racomitrium lanuginosum*) and/or lichens (e.g. *Cladonia* species); and siliceous alpine and boreal grasslands with stiff sedge *Carex bigelowii* and moss heaths. Rarer vegetation types include snowbed communities with dwarf willow *Salix herbacea* and various bryophytes and lichens, and sub-arctic willow scrub (as described in McLeod *et al* 2005).

Montane habitats are extensive in the Scottish Highlands, but are highly localised in England and Wales and they tend to be relatively small and fragmented, supporting a more limited range of species. They are significant because they are at the southern-most limit of their range in Britain. These habitats have not been fully surveyed, but it is estimated that they cover approximately 2,300 ha in England. There is some evidence that the English protected area network (SSSIs) is generally well placed to take advantage of environmental characteristics that increase the potential of landscapes to act as refugia (Suggitt *et al* 2014).

Potential climate change impacts

Cause	Consequence	Potential impacts
Increased mean temperatures	Longer growing season Warmer summers	■ Increased growth of grasses and dwarf shrub species could lead to these out-competing montane heathland species, especially mosses and lichens. ■ Temperature is frequently a limiting factor for insect and microbial performance. Warmer temperatures are likely to result in increased herbivory and faster nutrient cycling.
Hotter summers	Possible increase in visitor numbers	■ Higher visitor numbers could lead to increased erosion on access routes and increased chance of a wildfire event. (Albertson *et al* 2010).
Drier summers	Drought Drier ground conditions	■ Drier conditions could lead to changes in community composition, increased susceptibility to wildfire, and greater susceptibility to peat and soil damage following wildfire. ■ Drier conditions could make upland areas more accessible for visitors, exacerbating existing problems of erosion and fire risk.
Wetter winters	Increased surface runoff	■ Higher surface run-off could increase erosion, particularly on footpaths and on mountain summits. ■ Higher rainfall could benefit some plant communities that occur on leached soils.
Storm events	Increased rainfall intensity	■ Increased erosion (see above).
In combination		■ Climate change could result in a loss of suitable climate for key species such as dwarf willow *Salix herbacea*, trailing azalea *Loiseleuria procumbens* and montane lichens (Holman *et al* 2002; Berry *et al* 2005). It could also lead to the local extinction of the mountain ringlet butterfly *Erebia epiphron*, which, in England, is only found in the Lake District. ■ Increased winter rainfall and milder conditions may adversely affect arctic species, such as Alpine forget-me-not *Myosotis alpestris*, which thrive under winter snow cover but cannot withstand longer periods of damp conditions (Elkington, T.T. 1962).
Global impacts	Potential changes to the economics of upland grazing and shooting systems	■ Some alpine heaths have been shown to require grazing to survive and could be lost if grazing is removed (Miller, G.R. *et al* 2010).

Adaptation responses

The distribution and condition of many montane communities has been heavily influenced by over-grazing, trampling, Victorian plant collecting, and nitrogen-deposition. Reducing these pressures and allowing the habitat to recover may help to reduce their vulnerability to climate change, though there is a possibility that upland generalist species will grow more and out compete the rarities, leading to the development of acid grassland and upland heath.

Most of the arctic alpine flora is limited by competition, rather than an inability to tolerate higher temperatures, and it may be possible to exploit this. In cases of extreme rarity, direct, targeted management to remove or limit the growth of more competitive species is worth considering. It may also be possible to adjust grazing to ensure that sward height does not become too high and prevent scrub encroachment, although this is difficult in an extensively managed system.

Some species will suffer declines due to climate change (e.g. alpine saxifrage *Saxifraga nivalis*), but for others (e.g. purple saxifrage *Saxifraga oppositifolia* and mossy saxifrage *Saxifraga bryoides*), where non-climatic factors are more important, appropriate management can limit any decline. Monitoring and research is required to identify changes in community composition, species distribution and abundance and to determine the causes of any future change.

Microclimate variability can be very large in mountain areas, with large differences in temperature between north and south facing slopes, as well as with altitude. Cold air drainage can also create temperature inversions with lower than expected temperatures in localised pockets. Recognising such small scale refugia, ensuring their protection and prioritising the reduction of other pressures in these areas, may be the most effective element of adaptation in a local area.

While at the present time it would be premature to simply accept the loss of a species vulnerable to climate change in these habitats, it is important to take a view on the status of the species and communities across their whole range. This will allow decisions to be made that prioritise action where the need is greatest and the chances of success are highest.

Some of the potential adaptation options for this habitat are outlined below.

- Ensure appropriate management through the control of grazing. Many of these habitats would naturally be controlled by climate and not grazing management, so shepherding and (where appropriate) fencing can be used to exclude livestock from sensitive areas. Changing climate may change the optimum stocking density required to maintain montane community composition (for example, grass growth will increase with longer growing seasons and higher temperatures), so flexibility is needed.
- Develop fire contingency plans across the whole upland habitat mosaic, to include adapting the design and management of habitats to reduce fire risk, and closing some areas at times of high risk.
- Minimise erosion through the management of access and grazing.
- Within individual upland units or sites, identify areas that might act as potential refugia from the impacts of climate change, such as areas with north facing slopes, complex micro-topography, robust hydrology, or high species diversity, and ensure that these are managed appropriately.
- Maintain the full diversity of montane habitats to provide a wide range of micro habitats and niches, including, where possible, bare rock and areas characterised by mosses and lichens, low herbs, dwarf shrubs of diverse age classes, wet heath and mire, and scattered trees and shrubs.
- Take the whole of the species range into account in deciding the priority attached to intensive conservation measures in a particular location.
- Translocation to establish new populations of species in climatically suitable locations which are likely to remain so in future might be considered. Although this would require a detailed study and would be dealt with on a case by case basis.
- When developing management plans, consider the wider mosaic of upland habitats and not just montane habitats in isolation.

The loss of suitable climate space could lead to the local extinction of the mountain ringlet butterfly
© Richard Revels (rspb-images.com)

Relevant Countryside Stewardship options

UP3 Management of moorland

This option aims to maintain and restore moorland priority habitats and ecosystem function, species, protect historic features and strengthen landscape character.

UP6 Upland livestock exclusion supplement

This option aims to improve habitat and feature condition through complete removal of livestock for at least four months, often the winter grazing period.

Further information and advice

Natural England (2001) Upland Management Handbook
The upland management handbook pools the expertise of many of the country's leading wildlife, farming and land management specialists to provide a blueprint for the practical delivery of land management that will benefit upland wildlife.

Tayside Biodiversity Partnership Montane (habitats above the treeline).

Natural England (2008) Responding to the impacts of climate change on the natural environment: Cumbria High Fells (NE115) Report – this is a study undertaken by Natural England to assess the vulnerability of the Cumbria High Fells National Character Area to climate change and identify possible adaptation responses.

JNCC (2008) UK BAP habitat description Mountain Heaths and Willow Scrub.

Key evidence documents

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Sand Dunes at Holkham NNR, Norfolk.
© Natural England/Allan Drewitt

27. Coastal sand dunes

Climate Change Sensitivity: **Medium**

Introduction

Sand dunes have potential to adapt to some impacts of climate change through natural sediment processes. (Rees *et al* 2010). Unfortunately, past and present interventions have often reduced or constrained sediment processes, while built development has reduced the ability of dunes to migrate landwards, both resulting in a reduced capacity for adaptation. Dunes are therefore likely to be more susceptible to climate change where space and sediment are limited. Sea level rise and changes in the coastal movement of sediment are projected to contribute a 2% loss in area between 1999 and 2020 within the UK (Jones *et al*. 2011). These projections need more data to validate them in England.

Habitat Description

Dunes are formed where intertidal beach plains dry out and sand grains are blown inland. Formation starts when dune-building vegetation colonises deposits above the high tide mark. Over time, these can develop into complex landforms of dune ridges and hollows ('slacks'). Physical, climatic and coastal processes influence topography, hydrology and vegetation. Most current English dune systems originated about 6000 years ago.

Phases of mobility and natural coastal dynamics lead to a sequence of dune vegetation types, which increase in stability further from the sea, reflecting the development of soils and vegetation (Jones *et al* 2011).

Sand dune communities vary geographically, reflecting both the distribution of species and as a consequence of the chemical properties of the sand. For example, lyme grass *Leymus arenarius* has a more northerly distribution, growing alongside marram grass in mobile dunes; while wild thyme *Thymus polytrichus* is found on base-rich sands, typically found in south-west England, where shell fragments are present within the beach material.

Sand dunes form in relatively exposed locations, and in a number of physiographic situations. Major dune systems are widely distributed around the English coast, with the major concentrations and largest sites on the north-east, north-west and south-west coasts. The most common are bay dunes, where a limited sand supply is trapped between two headlands e.g. Druridge Bay, Northumberland; spit dunes, which form as sandy promontories at the mouths of estuaries e.g. Spurn Point, East Yorkshire; and hindshore dunes, which occur in the most exposed locations where large quantities of sand are driven some distance inland, over a low-lying hinterland e.g. Sefton Coast, Merseyside. The total area of sand dunes in England is approximately 11,897 ha (Radley 1994).

Potential climate change impacts

Cause	Consequence	Potential impacts
Sea Level Rise Increased frequency of storms	Altered coastal dynamics	■ Changes to the amount of sediment being supplied and removed from dunes.
	Increased erosion	■ Beach lowering and steepening of the foreshore. ■ Changes in dune hydrology can affect the flow of water from dune slacks. ■ Changes in shoreline position and dune system area are likely to affect sand stability, dune mobility, and groundwater levels and flow patterns, which, in turn, will affect the ecology of dune habitats. ■ If beach plains are narrower or wetter there is likely to be less wind-blown sand. ■ Species assemblages will change, affecting bird and mammal food sources. ■ In combination with hard sea defences, coastal dynamics will change, with loss of sediment exchange between the beach plain and dune system; and a lowering of beach levels. This leads to increased wave energy causing more erosion to the dune face and net loss of habitat.
Higher annual average temperatures	Longer growing season	■ Dune systems may become more stable due to warmer temperatures favouring growth of dune grasses, and exacerbated by Nitrogen deposition (Mossman *et al* 2013, Jones *et al* 2008) increasing the rate of successional change. ■ Increased stabilisation of dune systems and soil development (Rees *et al* 2010).
Drier summers	Drought	■ Lower dune water tables (Clarke & Sanitwong 2010). The associated drying out of dune slacks would lead to the loss of specialist species. ■ Increased drying of sand may lead to more wind-blown sand, leading to dune expansion, the creation of new blow outs, and more early successional stage habitat.
Wetter winters	Wetter winters	■ Wetter conditions could prevent beach plains from drying out. Wet sand is less likely to be moved by the wind, which can affect dune processes and consequently the dune vegetation.

Adaptation responses

Sand dunes are a component of dynamic coastal systems, and much of the emphasis on adaptation at the coast has been to maintain the natural coastal processes where possible; including through managed realignment. Under this approach, sand dunes will be lost in some places but develop in others. In the long-term this is likely to be the most important response. However, some on-site actions to increase the resilience and diversity of dune systems are also possible.

Some of the potential adaptation options for this habitat are outlined below.

- Restore or maintain habitat in favourable condition and ensure that non-climatic pressures are reduced.
- Manage recreational use to prevent excessive pressure on vegetation, by rotational exclusion of people, especially from fore-dunes and fixed dunes, and by retaining vegetation that can trap sand.

- Minimise large-scale surface sand erosion on fixed dunes through flexible management For example by adjusting stocking density and the timing of grazing in response to seasonal variation in growing conditions, while maintaining a proportion of bare sand.
- Manage dunes to maintain the full range of successional stages, avoiding a build-up of organic soil layers and the development of coarse grassland and scrub.
- Where possible ensure hydrological conditions are fully conserved to offset potential reductions in rainfall. Reduce abstraction pressures and ensure maximum recharge of dune water tables by reducing the impacts of scrub, trees and coarse grassland.
- Develop management plans that respond to predicted changes across the whole coast and not individual sites in isolation.
- Anticipate and develop approaches to managing the landward movement of dune systems, which will require consideration of the impacts on adjacent agricultural land.
- Adopt a strategic approach to coastal planning and develop an understanding of the sediment budget, to ensure there is adequate space for dune systems to migrate, and that there is a continued supply of sediment.
- Adjust designated site boundaries and interest features as coasts evolve, with the aim of enlarging functional units.
- Plan for the relocation of human assets in flood or erosion risk areas. The future of dune golf courses will need to be specifically addressed.

The Natterjack toad is found in a handful of places and breeds in warm shallow ponds in sand dunes and sandy heaths.
© Natural England/Peter Roworth

Relevant Countryside Stewardship options

CT1 Management of coastal sand dunes and vegetated shingle

This option aims to ensure the appropriate management of existing coastal sand dune and vegetated shingle sites, whether in good condition or needing restoration.

CT2 Creation of coastal sand dunes and vegetated shingle on arable land and improved grassland

This option aims to create sand dunes and coastal vegetated shingle on arable land or improved grassland locations which were formerly part of sand dune or shingle systems, or are adjacent to such active systems.

Further information and advice

The Sand Dune and Shingle Network
Based at Liverpool's Hope University, the aim of the Sand Dune and Shingle Network is to conserve sand dunes and shingle as dynamic landscapes.

Marine Climate Change Impacts Partnership
Coastal and inter-tidal habitats chapters in **MCCIP Impacts Report Card 2010/11**.

JNCC (2008) UK BAP habitat description Coastal Sand Dunes.

Relevant case study examples

Sefton Coast Adaptation Study
This adaptation study considers the potential impacts of coastal change, including climate change, on the Sefton Coast. It identifies the risks and opportunities arising from coastal change helping to highlight the issue of coastal change for partners so that they can consider options and how these might be included in policies and management plans.

National Trust - Shifting Shores (2015). This report outlines the National Trust's approach to adaptation at the coast. It follows a report commissioned in 2005, which looked at how coastal erosion and flooding might affect its coastal properties over the next 100 years.

Key evidence documents

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Rees S, Angus S, Rhind P & Doody JP. (2010) **Coastal Margin Habitats** in MCCIP Annual Report Card 2010-11, MCCIP Science Review, 21pp.

Saltmarsh at Lymington, Hampshire.
© Natural England/Peter Wakely

28. Coastal saltmarsh

Climate Change Sensitivity: **High**

Introduction

Saltmarshes are particularly sensitive to the combined impacts of sea level rise, storm events and human responses to these, as they occupy a narrow strip between the marine and terrestrial environments. Saltmarsh can be lost due to coastal squeeze, where they are inhibited by hard sea defences and unable to roll back naturally. Saltmarshes exist as part of a wider coastal sedimentary system, so factors influencing the function of estuaries and barrier coasts will impact on this element of the intertidal habitat, with the potential for abrupt changes (Mieszkowska, 2010).

Relative sea level rise (taking account of isostatic changes), storm events, and changes in the availability and movement of sediment are already having effects on saltmarsh, and climate change projections indicate that this will increase. The impacts of a rising sea level on saltmarsh community composition and area are likely to be greater than those of temperature and rainfall. Saltmarsh communities are adapted to a transient environment, and where there is sufficient sediment may accrete vertically (Hughes 2004) or, where space is available, migrate inland (Mossman *et al* 2013), so there is potential for adaptation measures to reduce risks.

Habitat Description

Coastal saltmarshes comprise the upper, vegetated portions of intertidal mudflats, lying approximately between mean high water neap tides and mean high water spring tides.

The development of saltmarsh vegetation is dependent on the presence of intertidal mudflats and is usually restricted to comparatively sheltered locations in estuaries, saline lagoons, behind barrier islands, and on beach plains. Saltmarsh vegetation consists of a limited number of salt tolerant (halophytic) species adapted to regular immersion by the tides, together with a range of plants that are more widespread, but which can tolerate infrequent immersion (Glycophytes) (Rodwell 2000). A natural saltmarsh system shows a clear zonation according to the frequency of inundation. At the lowest level, the pioneer glassworts *Salicornia spp*. can withstand immersion by as many as 600 tides per year, while the upper marsh only experiences occasional inundation on the highest tides and is more species-rich.

Saltmarsh plant communities can be divided into species-poor low-mid marsh, and the more diverse communities of the mid-upper marsh. There are regional variations, which can reflect the age of the saltmarsh and the types of management that is present or has occurred in the past. Where grazing has been practised, saltmarsh vegetation is shorter and dominated by grasses. At the upper tidal limits, saltmarsh communities grade into drift line, swamp, or transitional communities which can only withstand occasional inundation. Saltmarsh communities are additionally affected by differences in climate, the particle size of the sediment, freshwater seepages into the intertidal zone and, within estuaries, by decreasing salinity in the upper reaches. Saltmarshes on fine sediments, which are predominant on the east coasts of Britain, tend to differ in species and community composition from those on the more sandy sediments typical of the west. The northern limits of some saltmarsh species also influence plant community variation between the north and south of Britain.

The Alkborough Flats re-alignment scheme in North Lincolnshire will reduce flood risk and create new habitats.
© Natural England/Peter Roworth

Saltmarshes are an important resource for birds and other wildlife. They act as high tide refuges for birds feeding on adjacent mudflats, as breeding sites for waders and gulls, and the seeds of annual saltmarsh plants provide a source of food for passerine birds, particularly in autumn and winter. In winter, saltmarshes with shorter vegetation (often also grazed by livestock) are used as feeding grounds by large flocks of wildfowl. Areas with high structural and plant diversity, particularly where freshwater seepages provide a transition from fresh to brackish conditions, are particularly important for invertebrates. Saltmarsh creeks and flooded areas at high tide also provide sheltered nursery sites for several species of fish, which exhibit a high degree of site fidelity and a degree of seasonal use (Green *et al* 2009).

Since medieval times, many saltmarshes and associated intertidal areas have been reduced in extent by land claim. As a consequence, many saltmarshes now adjoin arable land, and the upper and transitional zones of saltmarshes are scarce in England. Sites still displaying a full range of zonation are particularly valuable for nature conservation.

Saltmarshes are concentrated in the major estuaries of low-lying land in eastern and north-west England and on the border with Wales, with smaller areas in the estuaries and sheltered parts of the coast of southern and north east England. There are an estimated 32,462 ha of saltmarsh in England.

Potential climate change impacts

Saltmarsh is one of a number of coastal habitats that are threatened by rising sea levels and increased storm events, combined in some areas with isostatic change. The impact of sea level rise is exacerbated by hard sea defences which prevent new habitat from forming to replace what is lost.

Cause	Consequence	Potential impacts
Sea Level Rise	Altered coastal dynamics and changes to the amount of sediment supplied	■ The area of saltmarsh is likely to be reduced or lost. ■ Where sediment loading is sufficient, rates of vertical accretion can keep pace with sea level rise (Hughes 2004; Mossman *et al* 2013). ■ Where space exists inland migration of salt marsh can also take place, but this is restricted in many parts of England by hard sea defences.
	Increased frequency of inundation and water-logging	■ Inundation and water-logging can result in an increased area of exposed mud, leading to greater susceptibility to invasive plants and erosion; increased water-logging at low tide; and potential impacts on soil processes and community composition (Davy *et al* 2011).
	Increased erosion	■ Erosion at seaward margin, with no sediment transfer higher into the marsh, can cause plants to die back. ■ A steepening of the marsh and foreshore profile, which could lead to more wave energy reaching the saltmarsh (Mossman *et al* 2013). ■ A reduction in the area of saltmarsh where accretion is at a slower rate than sea level rise. ■ Increased fragmentation and internal dissection as creeks erode.
	Potential construction of new sea defences, and existing hard defences maintained to higher standards	■ A rise in flood defence standards could result in existing sea walls being enlarged and encroaching directly on saltmarsh, while new defences could result in changes to sediment dynamics and lead to the accumulated destruction of marshes. The loss of fronting marsh will increase the wave energy reaching sea walls, with impacts on maintenance costs.
	Changes in the relative climate space available to saltmarsh species	■ Changes to community composition, with an increase in graminoid[10] species over forbs[11] (Gedan & Bertness 2009). ■ Potential loss of suitable climate space for some key saltmarsh species e.g. Sea purslane *Atriplex portulacoides*, common saltmarsh grass *Puccinellia maritima* and Annual sea blite *Suaeda maritima* (Holman & Loveland 2001). ■ Sea heath *Frankenia laevis*, sea lavender (*Limonium vulgare* and *L. humile*) and common cord-grass *Spartina anglica* have the potential to expand from their current southerly distribution (Holman & Loveland 2001, Mossman *et al.* 2013). ■ Sea purslane is potentially the physiognomic dominant of saltmarshes and has been found to rapidly dominate some newly created managed realignments (Mossman, Davy & Grant 2012). Expansion of this potentially dominant species may lead to a shift in community structure.
Hotter summers	Increased evaporation	■ Increased salinity in the upper zones of marshes could result in changes to community composition and vegetative dieback (McKee *et al* 2004).
Drier summers	Drought	■ Drier conditions could lead to vegetative dieback in upper marshes, and changes in community composition due to competition from grassy species (Ewanchuk & Bertness 2004).
In combination	Increased nutrient loading due to increased erosion and run-off from adjacent agricultural land	■ Increased nutrient loading could lead to an increase in late-successional species and the dominance of graminoid species, such as sea couch Elytrigia atherica (van Wijnen & Bakker 1999; Bobbink & Hettelingh 2011; Mossman *et al* 2013).

10 Grasses, sedges and rushes.
11 Herbaceous species.

Adaptation responses

Although saltmarshes are sensitive to climate change, provided they have sufficient sediment supply and adaptation space they have considerable ability to adapt to changes in sea level. Being a component of dynamic coastal systems, adaptation is likely to focus on maintaining the natural coastal processes that provide the sediment to support saltmarsh. Ensuring that sufficient space is available for saltmarsh to develop naturally and migrate inland, and identifying sites for managed realignment to compensate for habitat lost will be key. It may also include the restoration of the coastal flood plain by removing or breaching artificial structures.

Some of the potential adaptation options for this habitat are outlined below.

- Act to eliminate or reduce non-climate change associated erosion. For example that caused by altered drainage flows, contamination, removal of sediment by dredging, or wash from shipping.
- Manage recreational pressure to minimise erosion and damage to saltmarsh vegetation. Consider using sediment re-charge to reduce the rate of erosion of vulnerable areas of saltmarsh, where longshore drift of sediment has been disrupted by human activity (French & Burningham 2009).
- Minimise surface erosion through flexible management. For example, where grazing is appropriate to the site, adjust stocking density and the timing of grazing regimes in response to seasonal variations in growing conditions, and ensure that overgrazing does not reduce the potential for accreting sediment (taller vegetation tends to trap more sediment, Andresen *et al* 1990).
- Ensure that adaptation through the use of hard defences does not adversely affect coastal dynamics and increase the threat of coastal squeeze.
- Develop and implement management plans that respond to predicted changes along the whole coast, not individual sites in isolation.
- Anticipate and develop approaches to managing the landward movement of marshes by identifying and protecting priority sites for realignment projects.
- Ensure adequate space and promote policies that allow a continued supply of sediment (e.g. from eroding cliffs) for replenishing saltmarsh, through strategic coastal planning.
- Adjust the boundaries and interest features of protected sites as coasts evolve, and aim to enlarge functional units.

Relevant Countryside Stewardship options

CT3 Management of coastal saltmarsh

This option aims to maintain coastal saltmarsh in good condition and restore saltmarsh in unfavourable condition where vegetation management is a key factor.

CT5 Creation of inter-tidal and saline habitat by non-intervention

This option aims to create inter-tidal and saline habitat, including transitional areas, following the unmanaged breach of sea walls or the overtopping of sea walls.

Further information and advice

Environment Agency (2007) **Saltmarsh management manual**.

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Abbotts Hall Farm – Essex Wildlife Trust
The Abbotts Hall Farm project on the Blackwater Estuary is a special managed realignment scheme, demonstrating how farming and nature conservation can work side by side.

Medmerry managed realignment scheme
The Medmerry managed realignment scheme has created a major new sea defence in West Sussex. This has improved the standard of flood protection and created important new intertidal wildlife habitat and recreational opportunities.

Alkborough Flats Tidal Defence Scheme, South Humber Estuary.

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Coastal lagoons at Keyhaven Marshes, Hampshire.
© Natural England/Philip Ray

29. Saline Lagoons

Climate Change Sensitivity: **High**

Introduction

The trends and changes in coastal margin habitats including saline lagoons have been described most recently by the UK National Ecosystem Assessment (Jones *et al* 2011b). Like other coastal habitats, saline lagoons are highly sensitive to the impacts of climate change, especially to relative sea level rise and increased storminess.

The physical, chemical and ecological characteristics of coastal saline lagoons are highly variable and the impacts of climate change are also likely to vary between sites. Naturally formed lagoons could have potential to adapt to climate change by migrating landwards with rising sea levels, but the cumulative impact of climate change and anthropogenic stressors, including past and present interventions that restrict sediment processes needed for such adaptive mechanisms, make saline lagoons particularly vulnerable. Consequently, saline lagoons have been identified as one of the most vulnerable habitats in England and Wales, requiring urgent action in order to mitigate against the impacts of climate change (Brazier *et al* 2016; Jones *et al* 2011a; Mitchell *et al* 2007).

Habitat Description

Coastal saline lagoons are areas of typically (but not exclusively) shallow, coastal, saline water, wholly or partially separated from the sea by sandbanks, shingle, engineered structures such as sluices or, less frequently, rocks or other hard substrata. They retain a proportion of their water at low tide and may develop as brackish, fully saline or hyper-saline water bodies (Angus 2016).

Saline lagoons are complex and dynamic habitats that can form naturally through percolation of sea water through sand or shingle barriers, or artificially through engineered barriers that cut off a part of an estuary or the sea from direct tidal influences and/or restrict tidal movement. Freshwater input to saline lagoons usually occurs from direct drainage of surrounding land or through groundwater seepage. Although coastal lagoons can contain a variety of substrata, they most commonly include soft sediments.

Coastal lagoons are highly variable in size, form, and salinity regime. Even within sites, the physical characteristics and salinity often vary seasonally and can also change over a longer time scale due to their ephemeral nature (Duck and deSilva 2012). The plant and animal communities found within lagoons vary according to the physical characteristics and salinity regime of the lagoon and can be broadly divided into three groups; marine species that are tolerant of low salinity, freshwater species that are tolerant of high salinity, and lagoon specialists (Bamber 2010).

Although a relatively limited range of species may be present in saline lagoons compared with other marine habitats, many species are adapted to the highly changeable conditions that occur in saline lagoons and some are either mainly or entirely restricted in their distribution to this habitat. Such specialist species include the lagoon sand shrimp *Gammarus insensibilis*, tentacled lagoon worm *Alkmaria romijni*, lagoon sea slug *Tenellia adspersa*, starlet sea anemone *Nematostella vectensis*, tentacled lagoon worm *Alkmaria romijni*, trembling sea-mat *Victorella pavida*, foxtail stonewort *Lamprothamnium papulosum* and bearded stonewort *Chara canescens*, all of which protected under the Wildlife and Countryside Act (1981) as amended. Furthermore, despite their limited extent compared to many other coastal habitats, saline lagoons provide a highly important resource for large numbers of birds that use the habitat for feeding, nesting and roosting at high tide.

In England, there are currently 177 coastal saline lagoons, covering an area of approximately 1300 ha, with 450 ha being occupied by a single site (The Fleet in Dorset). The rarity of this habitat and the specialist flora and fauna it supports make saline lagoons especially valuable for nature conservation. For this reason, many coastal saline lagoons in England are protected by national and international designations.

Potential climate change impacts

Saline lagoons are increasingly threatened by climate change. Reviews of the potential impacts of climate change have identified a number of significant risks including relative sea level rise, increased storminess and changes in temperature and/or seasonal precipitation, which can alter the distribution, ecology and functioning of lagoon habitats (Mossman *et al* 2015).

These risks are listed in the table below. It should be noted that as each lagoon is unique, the impacts of climate change on lagoons are likely to vary between sites based on their physical characteristics and salinity regime. Furthermore, the impacts will not be the same everywhere around the coast of England; for example sea level rise is predicted to be the greatest along the southern coast of England whereas lagoons in the north and west of England may be more susceptible to freshwater inundation due to increased risk of flooding.

Cause	Consequence	Potential impacts
Relative sea level rise (RSLR) and increased storminess	Altered coastal dynamics and changes to the amount of sediment supplied	■ Increases in the rate of sea level rise will substantially alter the sediment balance. Coastal systems are dynamic and have the potential to adapt to rising sea levels, but only if there is an adequate supply of sediment to allow accretion, and if there is landward space for the coast to roll-back into. Sea defences and other coastal management interrupt the movement of sediment between systems and prevent natural coastal realignment. ■ The behaviour of any coastal sediment will change with increasing rates of RSLR, but sites will differ according to topography and sediment supply. There will be a tendency for shingle impoundments to migrate landwards as RSLR progresses but once RSLR exceeds a 'tipping point' around an annual rate of 3-4 mm, widespread reorganisation of coastal landforms, including lagoons, may occur (Rennie and Hansom 2011).
	Coastal Squeeze	■ Saline lagoons with natural barriers may be able to migrate with rising sea levels by barrier 'over-washing' and the transfer of sediment from the front to the rear of the barrier (Jones *et al* 2011b). ■ Policies that allow natural coastal rollback will cause losses of lagoon area unless the lagoons are able to migrate landward. In many cases, this is unlikely due to engineered barriers. This 'coastal squeeze' will diminish the extent of saline lagoons (Spencer and Brooks 2012). ■ Artificial lagoons will be entirely dependent on continued human intervention (Brazier *et al* 2016).

Cause	Consequence	Potential impacts
	Increased seawater inundation	■ Many lagoons are protected from tidal inundation by sand or shingle barriers. RSLR and increased storminess may result in increased frequency of breaching and overtopping of lagoon barriers. Seaward enclosing barriers may become increasingly susceptible to breaching or more extensive morphological collapse as sea-level rises and storminess potential increases (Lowe *et al* 2009). Even if barriers remain in place, changes in wave height and/or force may result in increased frequency of barrier over-washing. ■ Increased seawater inundation may lead to increased and/or less variable salinity levels in lagoons. While most lagoon organisms have optimal salinity regimes, they also tend to have wide salinity tolerance, especially as adults. The problem of increasing salinity for lagoon invertebrates is that most, if not all, have close marine counterparts, which are likely to out-compete them at salinities close to that of pure seawater (Angus 2016). As a result, the lagoon community composition and diversity may be drastically altered as a result of increased seawater inundation. ■ Increased seawater inundation may lead to changes in water quality, which may have a negative impact on the diversity and composition of lagoon species.
Drier summers and increased annual average temperatures	Changes in seasonal water availability	■ During drier and/or warmer periods, (most likely in southern Britain), an increase in hypersaline conditions is likely as water evaporates from lagoons (Mitchell *et al* 2007). A different suite of species tolerant of these conditions may become evident. ■ Increased summer temperatures may lead to increased drying out and an increased level of desiccation in the intertidal area, restricting the distribution of intertidal species (NIHAP 2003), depending on precipitation amounts.
Wetter winters	Increased seasonal precipitation	■ Climate change models suggest that most regions in northern Europe will experience wetter winters in the future, with increased frequency of flooding events in coastal areas (McClatchey *et al* 2014). Changes in the volume and timing of freshwater discharge into lagoons due to higher precipitation has the potential to alter the salinity regime of the lagoon, which combined with potentially more frequent overtopping during storms will lead to changes in water chemistry. A reduction of salinity may occur where the balance shifts towards higher input of freshwater, and will result in a shift in species composition according to their tolerances. ■ Reduction in water quality may also have an impact on the diversity and composition of lagoon species. Lagoon water quality may be reduced as a result of increased nutrient runoff from the surrounding land caused by increased precipitation and more frequent flooding (Anthony *et al* 2009).
Changes in seawater temperature	Changes in lagoon water temperature	■ Warmer water could hasten the spread of invasive non-native species. For example, *Ficopomatus enigmaticus* is an annelid tubeworm which is thought to be at, or close to, its temperature minimum for maintaining populations and successful reproduction along the southern coast of Britain (Zibrowius & Thorp 1989; Thorp 1994). It was previously thought only to survive in artificially heated northern waters, but is now colonising lagoons along the south coast, such as Cockle Pond near Portsmouth Harbour.

Adaptation responses

Although coastal lagoons are highly sensitive to the impacts of climate change, naturally formed lagoons are ephemeral habitats that at least, in theory, have considerable ability to adapt provided there is space for adaptation with minimal human interference. However, saline lagoons do not exist in isolation but are part of the wider coastal system, which consists of a series of interconnected habitats including saltmarsh, coastal grazing marsh and estuaries, as well as smaller features such as shingle bars. In England, these dynamic habitat complexes have rarely escaped human influences, and coastal processes seldom operate in their fully natural state. The complex and dynamic processes between different coastal habitats also remain poorly understood (Mossman *et al* 2015).

Although there is a need for greater understanding about how coasts in England function in their entirety and the degree of naturalness that still remains within them (Beer and Joyce 2013), it is clear that adaptation responses for interconnected coastal habitats should consider the coast as a whole. It needs to be recognised that gains for some coastal habitats may mean the loss of others, but that there is also potential for the creation of new habitats to offset habitats that have been lost.

Three potential courses of action have been suggested as adaptation responses to climate change for coastal lagoons (Angus 2016):

1. Non-intervention, i.e. allowing processes to operate naturally. This option may mean that individual lagoons are formed, lost or relocated, or new and different coastal habitats are formed.
2. Manage the impacts of sea level rise by raising the height of the isolating barrier (if feasible and appropriate).
3. Translocation of vulnerable species to analogue sites. The success of this method is yet to be proven.

While option 1 is generally favoured, there is a risk that this could result in the local extinction of vulnerable lagoon species. Further research and monitoring is required for options 2 and 3 (Angus 2016).

Some of the potential adaptation options for this habitat are outlined below.

- Act to eliminate or reduce non-climate change associated pressures on coastal lagoons, including erosion caused by altered drainage flows or removal of sediment, eutrophication, heavy metal and synthetic contaminant exposure, marine litter and recreational pressures.
- Restore or maintain habitat so that it is in the best possible condition and better able to withstand external pressures caused by climate change.
- Anticipate future changes and develop approaches to managing the land adjacent to the lagoon, including identifying and protecting landward habitat for the lagoon to retreat to naturally as sea level rises.
- Adjust the boundaries and interest features of protected sites as coasts evolve, and aim to enlarge functional units.

Ringed plovers feed in the shallows and margins of saline lagoons. © Natural England/Allan Drewitt

- Sediment recharge may be considered on vulnerable areas, for example where the isolating barrier of a lagoon is a shingle ridge. However, the impact of sediment recharge on other coastal habitats needs to be carefully considered before proceeding with this option.
- Develop and implement management plans that respond to predicted changes along the whole coast and not in individual sites in isolation. As a part of a wider coastal management scheme, a lagoon may need to be allowed to move naturally or even to be lost entirely and recreated elsewhere if appropriate.

Relevant Stewardship options

CT3 Management of coastal saltmarsh

This option can include small lagoons if they are part of the saltmarsh area. The precise management agreed will depend on the particular conditions on a site. It could include maintaining an appropriate grazing regime around the lagoon, restrictions on the use of fertilisers on adjacent land, appropriate land drainage and controlling damaging activities associated with public access. This option will contribute to climate change adaptation and help to conserve and strengthen the distinctive local character of estuarine and coastal landscapes.

CT4 Creation of inter-tidal and saline habitat on arable land

CT5 Creation of inter-tidal and saline habitat by non-intervention

CT7 Creation of inter-tidal and saline habitat on intensive grassland

These options run for 20 years instead of the standard 5 years, in recognition of the level of management change involved and their largely irreversible nature.

These options create inter-tidal and saline habitats, including transitional areas (transitions between saltmarsh and nearby habitats), on arable land, improved grassland or following the unmanaged breach of sea walls or the overtopping of sea walls. As a result of tides bringing in sediment and seeds, a range of inter-tidal habitats will form such as mudflats and coastal saltmarsh, together with saline lagoons and transitions between these and other habitats. These habitats will benefit many specialised plants and animals adapted to the differing degrees of tidal inundation and saline influence. These factors result in variations in vegetation cover from bare mud to dense saltmarsh, and succession between them over time.

The creation of small-scale saline lagoons, which require an input of seawater, can be promoted by these options. They will also contribute to more sustainable flood management, adaptation to climate change and enhancement of the coastal landscape.

Further information and advice

Countryside Stewardship scheme details and management options.

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Relevant Case Studies

The Wallasea Island Wild Coast Project
The RSPB's Wallasea Island Wild Coast Project in Essex aims to combat the threats from climate change and coastal flooding by creating a large area of inter-tidal habitats, including mudflats and saltmarsh, lagoons and pasture. It will also help to compensate for the loss of such tidal habitats elsewhere in England. A range of features have been incorporated into the design to benefit wintering and passage SPA water birds. Islands have been created to provide high-tide roosts for waders, and nest sites for terns and spoonbills. Areas of saline lagoon and lowland wet grassland are being created to provide additional feeding areas for birds when the intertidal mud is covered at high tide.

For further information see **The Nature of Climate Change**, page 39 – 41.

Medmerry managed realignment scheme
The realignment scheme at Medmerry in Sussex is one of the largest managed realignment projects in the UK and the first of any notable size to be undertaken on an open coast. It is unique because it is the first scheme in the UK to be created by excavating a breach through a mobile shingle barrier.

The scheme was designed to provide the local community with sustainable flood and coastal protection (to a 1 in 100 year standard), as well as creating new intertidal habitat (mudflats, saltmarsh and lagoons) that was needed to compensate for losses of these habitats across the Solent. It was also designed to provide recreation space for visitors and local people.

It was completed in September 2013 and proved to be successful in achieving its goals. In particular it withstood the severe sequence of storms that hit the UK coastline during 2013/14. Around 185 ha of intertidal habitats were formed (along with transitional grassland and farmland) inside 4 miles of new flood protection embankments.

Steart Marshes

Steart Marshes in Somerset is a habitat creation project managed jointly by the Environment Agency and the Wildfowl and Wetlands Trust. Here, the issues of flood risk management, coastal squeeze and sea-level rise are being addressed by the creation of new areas of habitat, including saltmarsh, coastal grazing marsh, lagoons and mudflats.

Mapping coastal change at Cley/Salthouse and North Norfolk Lagoons

The lagoons at Cley are percolation lagoons, and depend on a shingle ridge which acts as the isolating barrier to regulate seawater intake. Prior to 2006, this shingle ridge was artificially profiled and prevented from migrating landwards, but in 2006, as a flood risk management measure, the Environment Agency and Natural England agreed to restore it to a more natural beach profile. The impact of this management decision has been monitored, using archive and newly commissioned LIDAR data.

In December 2013, parts of the UK experienced the biggest storm surge in 60 years, which was followed by another storm surge in January 2017. The coast of East Anglia was one of the hardest hit areas and has offered an opportunity to investigate how a coastline evolves naturally in response to change.

© Natural England/Andy Millar

The use of novel remote sensing techniques has enabled mapping of the storm surge breaches and sediment transport on engineered and gravel barriers that separate the saline lagoons from the sea. Researchers from the Centre for Environment, Fisheries & Aquaculture Science (Cefas) and the University of East Anglia have studied newly obtained aerial images of the area that were affected by the surge on December 2013. The impacted coastline encompasses the Wash and North Norfolk Coast European Marine Site (EMS) with its several designated saline lagoons, including the lagoons at Cley marshes that comprise 36% of the lagoon area within the EMS. The research has revealed widespread, long-term changes to parts of England's eastern coastline caused by the surge, including damage to the engineered and natural defenses and saltwater flooding in the lagoons. Sediment was transported for over 100 meters inland, in places infilling protected saline lagoon habitats.

The above photograph shows the landward side of the shingle ridge at Cley following the 2017 storm surge. A large, new outwash fan and proto-lagoon in its lee can be clearly seen. Some existing SAC lagoons were completely rolled over and have disappeared.

For further information see **Natural England (2011)** pp. 14 -23.

Increasing the Resilience of the UK's Special Protection Areas to Climate Change
Saline lagoons are important feeding, breeding and roosting habitat for many bird species, and many form part of European designated Special Protection Areas (SPAs). A **report** commissioned by Natural England in 2016 considered the ecological consequences of climate change for Special Protection Areas (SPAs). A series of case studies was developed to highlight how current management might be adapted at site level to address future climate change impacts, including at **Minsmere - Walberswick** in Suffolk and the North Norfolk Coast.

At Minsmere-Walberswick, proposed management responses include increasing control over water levels and salinity through adjusting inputs of freshwater and sea water (where possible); and on the Norfolk coast, the creation of shallow saline water bodies as part of management realignment schemes, and allowing saline lagoons to develop naturally where the local topography allows it (Franks *et al* 2016,a,b).

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Hunstanton Cliffs, Norfolk.
© Natural England/Naomi Stevenson

30. Maritime cliffs and slopes

Climate Change Sensitivity: **High**

Introduction

The Natural Environment chapter of the **UK Climate Change Risk Assessment Evidence Report** (Brown *et al* 2016) highlights that all coastal ecosystems are at high risk from climate change, with increased vulnerability in many locations due to the presence of flood defence and erosion protection structures, which prevent landwards rollback of the intertidal zone as a natural response to sea-level rise. In addition, natural adaptive capacity is limited by reduced sediment supply due to hard coastal defences. Dynamic coastal systems have the potential to be self-regulating in the face of rising sea levels. This can only occur if there is both an adequate supply of sediment and there is landward space for migration and adjustment of the different components relative to the tidal and wave energy frame.

Maritime Cliff and Slope environments will be affected by the consequences of climate change in a range of ways. It is quite natural for sea cliffs to respond to wave energy by releasing rocks and other sediment to the sea: this forms beaches at the cliff foot and is also transported by longshore drift to form sedimentary coastal habitats and beaches elsewhere. Climate change impacts from increased sea levels and wave height, and extremes of rainfall, are likely to alter patterns of both marine erosion and groundwater levels, and the latter will also increase risk of landslides. Where this risk affects built assets, there is likely to be increased demand to stabilise eroding cliffs by drainage and engineering measures. This will affect the environmental quality of the cliff habitats and sediment transfer to other coastal habitats. It is already considered that sediment inputs are reduced because of existing coast protection[12] measures (Lee 2001a).

Geology is the key factor in considering the potential effects of coastal erosion. The older and more resistant rocks are located in north west England and parts of the south west, and are relatively resistant to erosion. Younger sedimentary rocks are less resistant, and areas of glacial sediments are particularly prone to marine erosion and landslides. These areas include the east, southeast and south of England (Zambosky 2011).The greatest climate change impacts, and the most dramatic landslide events, are likely to be on soft cliffs rather than hard rock cliffs (McInnes and Moore 2007).

Climate change could alter the distribution of species through temperature changes, which may encourage non-native invasive species, but this is an area where more research is needed.

Likely changes identified in the Marine Climate Change Impacts Partnership (MCCIP) **Report Card** (Rees *et al* 2010) include:

- Increased marine erosion at cliff toes with higher sea levels and more frequent storms.
- Rocky shore platforms at the foot of hard cliffs may have more marine scour and wave attack at the cliff foot due to beach lowering, and may be lost with sea-level rise as they cannot accrete like beaches.
- Headlands form natural hard points and may promote changes in the shape of intervening bays and beaches.
- High levels of winter rainfall may promote greater risk of landslides, leading to more demands for coast protection.

12 'Coast protection' is defined as engineering measures to prevent or reduce the risk of erosion of the coast, usually in the form of hard structures combined with measures such as drainage to limit landslide risk.

- Old landslide complexes are likely to reactivate more rapidly than expected as groundwater pressure increases.
- Warmer temperatures may favour invasive species e.g. Hottentot fig *Carpobrotus edulis* , but may also promote suitable conditions for other thermophilic species.
- The balance of bare ground to successional vegetation may be altered on soft cliffs, with a potential loss of mosaic habitats important for scarce invertebrates.
- Changes in the intensity of agricultural or recreational use of cliff top land may reduce the potential for colonisation of eroding slopes by semi-natural vegetation.

Beach levels influence cliff erosion rates. As relative sea-level rise results in narrower, shallower beaches this may increase the retreat of soft cliffs in particular. Stabilising cliffs can affect beach sediment volume, further compromising beach levels along the coast and beyond the location of structures. Soft cliff erosion rates are extremely varied within and between years, but the majority of loss occurs in winter months. Excessive rainfall triggers slippages and retreat, so projected winter precipitation increases at a time when conditions promote erosion anyway, will result in higher recession rates. Masselink & Russell (2013) also conclude that it is it is very likely that currently eroding stretches of coast will experience increased erosion rates due to sea-level rise. The episodic nature of cliff recession, which would occur even without climate change, makes it difficult to predict the degree of additional future changes.

The habitat is very sensitive to the human response to coastal erosion, although more rapid recession could impact on the balance of vegetation and bare surfaces. Coastal erosion risk management attempts to stabilise these processes through a combination of toe protection, drainage, and other engineering methods. It is estimated that in the 100 years up to the 1990s, 860km of coast protection works were constructed to reduce erosion (Lee, 2001a), reducing sediment input by an estimated 50%. Schemes to extend or replace coast protection are still being proposed, often in response to the reactivation of landslides. Recently, high levels of rain have reactivated landslides on the Dorset coast at Lyme Regis, and Cayton Bay, Yorkshire

Soft cliff erosion is an important source of sediment. The areas with the most rapid rates of recession are on the south and east coasts of England. For example, at Holderness in Yorkshire cliff erosion is estimated to supply 3 million m^3 a year of fine sediment into the marine system, most of which is transported to the Lincolnshire coast and the Humber estuaries, contributing to the estuary environment (HR Wallingford 2002).

Habitat Description

Geology

It is estimated that there are approximately 1100 km of maritime cliffs and slopes in England (Rees *et al* 2010), and it is a relatively scarce habitat with a linear nature. Vegetated sea cliffs in England are very variable due to differences in geology, geomorphology, slope angle, abiotic processes, exposure and level of naturalness. It has been suggested that a minimum height for cliffs can be between 3 - 5m above the shore platform or beach (Barron *et al* 2011). In England the highest sea cliff is Great Hangman in Exmoor, Devon at 244 m, with the highest east coast cliff at Boulby in Yorkshire at 203 m.

Maritime cliffs and slopes have a series of steep or vertical faces as a result of slippage and erosion by marine processes (JNCC 2008). Wave action is the most important coastal process that drives change in sea cliffs. Changes in water depth and wave energy, and factors affecting long-shore drift and current movements, together with groundwater conditions, will determine the rate of sea cliff erosion and landward recession. The foot and tops of cliffs are also part of the overall ecosystem. At the foot, there can be a reef platform extending from the cliff foot into the intertidal and subtidal areas. This may also be covered by beach deposits. Cliff top habitats can have a maritime influence from blown salt spray and wave splash. This is greater on more exposed coastlines such as the south west. The type of cliff top habitat can influence the slope ecology, providing a source of plant seeds for the slope and additional habitat or food sources for a range of fauna, such as nectar for invertebrates.

Maritime cliffs can broadly be classified as 'hard cliffs' or 'soft cliffs', although in reality there can be complex mosaics and intermediate types.

Hard cliffs are found around the exposed coasts of the UK, mainly in the west. They have vertical or steeply sloping faces and thus support few higher plants, other than on ledges and in crevices or where a break in slope allows soil to accumulate. They tend to be formed of rocks resistant to weathering, such as granite, sandstone and limestone, but can be formed of softer rocks, such as chalk, which erode to a vertical profile. Vegetation types are well-described in the NVC (Rodwell 2000) as these have been well-studied.

Soft cliffs are found mainly on the east and south coasts of England. These are formed in less resistant rocks such as shales or in unconsolidated materials such as boulder clay or 'drift'. Their instability means seaward faces are less steep, sometimes with a series of steps, and can be colonised by vegetation. Soft cliffs experience frequent slumping and landslips, particularly where water percolates into the rock and reduces its effective shear strength (JNCC, 2008).

While different processes affect hard and soft cliffs, they are not entirely distinct; for example some hard rock types, such as chalk, may sporadically experience massive collapses (Hill *et al* 2002). These changes occur in a sequence of stages, with slope processes and marine erosion as the key influences.

Ecological variation

Maritime cliff and slope habitats are not uniform. Variation in geology, climate, location and exposure to wind and salt spray define the floral and faunal communities. Other key factors are the chemistry of the underlying rock, the water content and stability of the substrate and, on soft cliffs, the time elapsed since the last movement event. Plant communities in sheltered locations are more similar to those found inland, whereas those in exposed situations include more salt-tolerant species. Rock type is a significant factor defining the communities of cliffs and slopes (JNCC 2008).

The vertical faces and steep slopes of hard rock cliffs can be colonised by lichens and lower plants, but ledges and crevices support higher plant communities, some of which are unique to cliffs (Rodwell 2000). On hard rock cliffs, encrusting lichens are often the predominant vegetation at the lower levels in the wave splash zone, but other types can occur at other levels on cliffs. In extreme conditions, waves can lead to saline conditions on ledges or cliff tops, such that saltmarsh species can establish. In other areas, where cliffs occur adjacent to sand dunes on high energy coasts, windblown sand can accumulate on the cliff-slopes and tops (known as climbing and perched dunes), allowing dune species to colonise.

Where there is greatest exposure to the waves and winds, such as on the northern and south-western coasts, strictly maritime vegetation occurs. Here, species like rock samphire *Crithmum maritimum* and rock sea spurrey *Spergularia rupicola* occur. Where there are large colonies of cliff-nesting seabirds, their nesting ledges are enriched by guano and can support a particular community characterised by oraches *Atriplex spp.* and sea beet *Beta vulgaris spp. maritima*.

The vegetation of soft cliffs, which experience frequent slumping and landslips, forms in mosaics, and can include areas of recent slippage colonised by early successional communities as well as woodland on areas with prolonged (but not always permanent) stability (Hill *et al* 2002). Frequent slumping and slippages provide important nesting and feeding habitat for specialist invertebrates requiring soft substrates in open conditions. Seepages and springs associated with soft cliffs are also important invertebrate habitats (Whitehouse 2007).

Soft rock cliffs with no artificial coast protection are a rare resource in the British Isles and in Western Europe as a whole. It is estimated that only 256km of the English soft coast remains free of intervention. Soft rock cliffs often have shallow gradients which allow colonisation of vegetation and development of a wider range of habitats than on hard cliffs (Hill *et al* 2002). Species found here include a maritime form of red fescue *Festuca rubra*, thrift *Armeria maritima*, sea plantain *Plantago maritima*, buck's-horn plantain *P. coronopus* and sea carrot *Daucus carota spp gummifer*. Species of inland grasslands which also commonly occur in maritime grasslands include ribwort plantain *Plantago lanceolata*, bird's-foot trefoil *Lotus corniculatus*, and common restharrow *Ononis repens*, along with several species of grass.

Soft rock cliffs have long been known to support rare and notable invertebrates, particularly bees and wasps, beetles and flies. The ecological requirements of these species relate to the successional phases of cliff habitats, which are dependent on varying degrees of stability, and range from open bare ground to sheltered scrubby patches with nectar-rich plant species (Rees *et al* 2013).

Bempton Cliffs. © Natural England/Peter Wakely

Potential climate change impacts

Cause	Consequence	Potential impacts
Sea level rise	Greater levels of wave energy Altered coastal dynamics in long term	■ Increased marine erosion at cliff toes with higher sea levels and more frequent storms. With hard cliffs, rocky shore platforms may have more marine scour/wave attack at the cliff foot due to beach lowering, and may be lost with sea-level rise as they cannot accrete. ■ Headlands form natural hard points and may promote changes in the shape of intervening bays and beaches.
Increased storminess and more frequent extreme events	Greater levels of wave energy may reactivate landslides, and reduced time between storms could restrict the capacity for recovery	■ Loss of toe material at cliff foot, allowing landslides.
Increased annual average temperatures	Longer growing seasons and shorter winters	■ Warmer temperatures may favour invasive species e.g. Hottentot fig.
Hotter summers	Possible increase in visitor numbers	■ Changes in intensity of use of cliff top land may reduce the potential for colonisation of eroding slopes by semi-natural vegetation.
Drier summers	Clays and other friable substrates may dry and crack	■ Greater risk of erosion from collapses.
Increased winter rainfall	Increased rainfall may lead to higher groundwater levels, more water flowing over slope surfaces, and reduce the influence of salt spray	■ High levels of winter rainfall may promote greater risk of landslides, leading to more demands for coast protection. Old landslide complexes are likely to reactivate more rapidly than expected as groundwater pressure increases. ■ High winter rainfall combined with milder winter temperatures may extend the growing season and lead to increases in competitive plant species, particularly dominant grasses. ■ Less salt spray influence may change the balance of species on ledges and slopes.
Combination of causes		■ The balance of bare ground to successional vegetation may be altered on soft cliffs, with potential loss of mosaics important for scarce invertebrates.

Adaptation responses

Maritime cliff environments generally require limited management for nature conservation, and adaptation should focus on measures to work with the ongoing changes in cliff systems. Management plans should be developed with an understanding of the likely changes. Information about these may be available through a range of sources including Shoreline Management Plans (SMP), and tools that indicate erosion risk such as the Environment Agency's National Coastal Erosion Map. At all stages, coastal adaptation issues should be discussed with partners and stakeholders.

Where there are no existing erosion control measures, these should not be introduced, nor should drainage be installed on cliff slopes or cliff tops. The SMP policy will influence decisions on the maintenance or removal of any existing erosion control. Infrastructure, such as steps, cliff top fencing, paths etc. should be designed to be easily adapted, and its condition should be regularly reviewed. An understanding of the geological and geomorphological processes of the site in a wider context will be beneficial, as coastlines rarely function within individual ownership units.

Gannets at Bempton Cliffs, Yorkshire. © Natural England/ Andy Neale

An important aspect to consider is how the management of the cliff-top land will affect the cliff environment. Reversion to a semi-natural habitat type may be beneficial in the longer-term.

Generic guidance for considering adaptation of flood risk management infrastructure is provided in the **infrastructure report card** (Sayers and Dawson 2014).

Some of the potential adaptation options for this habitat are outlined below.

- Restore or maintain habitat in favourable condition and ensure that non-climatic pressures to maritime cliff and slopes (coastal defence works, quarrying, building construction, and recreational pressures etc.) are managed or reduced.
- Existing semi-natural habitats on cliff tops will be affected by erosion. This requires the development of strategies to re-create or expand these to account for future losses.
- Where intensive agricultural land is on the cliff top, a buffer area reverted to semi-natural habitat can promote greater resilience for cliff slope vegetation quality. Ideally, whole fields would benefit from reversion
- Develop information to support necessary adjustment of designated site boundaries and interest features as coasts evolve, allowing for between 30 to 50 years of change.
- Where features or buildings on the cliff top are within management control, ensure there is a clear plan for managing and recording historic or archaeological sites that may be at risk.
- Ensure that visitor management and recreation infrastructure planning takes account of coastal change and erosion risk, including using the 'roll-back' provision in the Coastal Access scheme to re-locate the England Coast Path route.
- Undertake more long-term or repeat studies on the impacts of increased rates of recession on cliff slope ecology.
- Monitor and control the spread of potential native and non-native invasive species.

Relevant Stewardship options

There are no specific options for cliffs. Grassland or heathland options may be suitable for cliff tops, but any issues of erosion leading to reduction in area during agreements must be agreed and addressed to ensure no loss of payments.

Further information and advice

Buglife **Soft Rock Cliff project**.

Natural England **Maritime Cliff and Slope Inventory** (NERR 003 2004/5).

MCCIP **Annual Report Card and Briefing Notes**.

Relevant case study examples

Natural England, **Coastal evolution in Suffolk: an evaluation of geomorphological and habitat change** ENRR647 (2006).

European Commission, **A guide to coastal erosion management practices in Europe: lessons learned** (2004).

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Zsamboky, M., Fernández-Bilbao, A., Smith, D., Knight, J., and Allan, J. 2011. Impacts of climate change on disadvantaged UK coastal communities. Joseph Rowntree Foundation.

Coastal vegetated shingle near Hurst Castle, Hampshire.
© Natural England/Philip Ray

31. Coastal vegetated shingle*

Climate Change Sensitivity: **High**

***** Note: this term covers all shingle features at the coast. Most will have some ephemeral seasonal vegetation. Larger systems will have more permanent perennial vegetation, often with a typical pattern of vegetation growth and including naturally bare shingle.

Introduction

The Natural Environment chapter of the **UK Climate Change Risk Assessment Evidence Report** (Brown, *et al* 2016) highlights that all coastal ecosystems are at high risk from climate change, with increased vulnerability in many locations due to the presence of flood defence and erosion protection structures, which prevent landwards rollback of the intertidal zone as a natural response to sea-level rise. In addition, natural adaptive capacity is limited by reduced sediment supply due to hard coastal defences. Dynamic coastal systems have the potential to be self-regulating in the face of rising sea levels. This can only occur if there is both an adequate supply of sediment, and there is landward space for migration and adjustment of the different components relative to the tidal and wave energy frame.

Studies have established that there is a relationship between the rate of shingle (gravel) barrier retreat by roll-over and the rate of sea level rise. A higher rate of sea level rise will be associated with faster landward movement. Storm events will affect shingle coastlines, leading to a changed form and location through wave transport of sediment, including 'over-washing' and breaching. The type and scale of change will vary between 'drift-aligned' (waves entering at an angle to the coast) or 'swash-aligned' (waves are perpendicular to the coast) shingle ridges. Most shingle systems in England now have limited amounts of new sediment.

Even without natural inputs of new sediment, some shingle systems have the potential to adapt to some impacts of climate change through adjustment of their form and moving landward, often in a series of steps driven by storm events of different intensity. However, past and present interventions affect morphology or constrain sediment processes. Any built development on their landward side will restrict capacity for adaptation. Coastal engineering to 'fix' shingle coastlines will not prevent major changes and may even exacerbate breakdown. Such coastlines are therefore likely to be more susceptible to climate change where space and sediment are limited.

Key issues affecting shingle coastlines are reduced availability of sediment resulting from the construction of coastal defences that limit longshore drift, and artificial management that reduces the capacity to adjust form, position and volume as sea levels rise. With just 4,276ha of this habitat type in England (Murdock *et al* 2010) it is important that existing locations are managed effectively at all locations in ways that take account of coastal processes. Analysis of recent change in England for key sites between 1990 and 2008 suggested a slight loss in overall area (~10% loss), with five sites showing net loss and four sites net gain (Murdock *et al* 2010).

Another factor to consider is the gradual wearing of individual shingle pebbles (Dornbush *et al* 2002). Rates of abrasion are influenced more by mean wave height than by mineralogy. Beach volume could therefore be reduced faster with higher wave energy. Inland of the active beaches, the impacts of climate change on shingle habitats will include increased drought, affecting both dry and wet habitats. Hotter summers may allow the establishment of invasive species, such as red valerian or other garden escapes.

A study of visitor preferences using a shingle location (Coombes and Jones 2010) concluded that climate change may influence future levels of recreational impact on coastal habitats via modifications in numbers and types of visitors. Overall, there is predicted to be an increase in visitor numbers to these localities, with greater participation in activities which are promoted by warm and dry weather conditions, such as sunbathing and paddling. Demands for such usage will need to be planned for, alongside changes in shingle morphology and potential breaches and overwashing events.

Jones *et al* (2013) point out that the scarce nature of this habitat leads to low rates of recolonisation after disturbance. Changes in patterns of precipitation or temperature will affect vegetation composition. Water retention is poor and evapo-transpiration is likely to increase year round, but particularly in autumn and summer, exacerbating the impact of summer droughts. Larger shingle structures supporting freshwater aquifers, such as Dungeness, may become vulnerable to saline water intrusion.

Habitat Description

Shingle (or gravel) beaches occur in high wave energy environments, with deposition of sediment driven by shingle supply through coastal processes. This is usually in the form of longshore drift, but 'swash-aligned' beaches have few, if any, inputs due to the direction of the waves. Sediment size ranges from 2-200mm diameter and can only be moved by waves, with storm events causing material to be shifted above the reach of normal waves. The primary source of the sediment is from glacial deposits pushed landward by rapidly rising seas after the last ice age. These are finite, and the material is transported by tidal currents. Long-term coastal evolution continues to occur as shorelines adjust after the last glaciation. Other sediment sources are from cliff erosion, with longshore drift taking sediment into beaches, bays, spits and nesses.

It is estimated that one third of the British coastline is fringed by shingle beaches (May and Hansom 2003), but very little of this can support vegetation growth other than a few annual plant species. Perennial vegetation can only grow once coastal processes have built up storm beaches above the high tide line. There are only 5,810 ha of vegetated shingle in the UK (Jones *et al* 2011), with around 40% occurring at just one site, Dungeness, in Kent (JNCC 2007).

Locations where shingle has been laid down will require a continuing supply of new material, or they will gradually reduce in extent. Although shingle systems are present around the UK coastline, it is a globally restricted habitat type, elsewhere mainly found in Japan and New Zealand. Some shingle bars formed in early post-glacial times are now partly covered by sand dunes as a result of rising sea levels leading to increased deposition of sand.

Shingle structures in their natural form are of significant geomorphological interest and some sites are notified for their active coastal geomorphology. Gravel barriers are distinctive coastal forms in which morphological inheritance and sediment sorting provide major controls on how they evolve. Coastal landforms can switch from being drift-aligned to swash-aligned in response to changes in sediment supply and volume. A drift-aligned shore needs constant supplies of sediment from longshore drift, whereas a swash-aligned shore re-works existing sediment but moves landward.

The primary beach ridges in particular contribute to flood risk management, especially in the south of England. The ability of a gravel ridge to slow wave run-up and absorb wave energy, as well as allowing water to percolate into it, provides the main flood risk management benefit rather than crest height. In some locations they have been managed to raise the crest height, but such practices are being reviewed in many cases. It is vital that the geomorphic controls and limitations on any system are fully understood, especially where gravel structures are present in a mosaic with other coastal habitats. Information about managing beaches in the context of reducing flood risk has been collated in the 2010 version of the Beach Management Manual (Rogers *et al* 2010).

In the UK, the largest areas are in the northwest, south and southeast. The shingle in the northwest tends to be associated with fringing beaches and spits and in the south east major structures such as Dungeness in Kent.

Ecology

The habitat type consists of vegetated and un-vegetated surfaces, both influenced by the overall morphology of the system. Typically, it is a combination of level or gently-sloping upper beaches exposed to salt-spray and periodic disturbance by storms and the highest tides, backed by a more stable landward area formed from previous beach ridges. Vegetation colonisation is influenced by the sorting of large and smaller particles and the ability of seed to establish in what is a very harsh environment. The extent of the landward area can vary from a few ridges on spit systems to several hundred on the larger formations, representing thousands of years of development.

Vegetation communities are described in Rodwell (2000) and in more detail in Sneddon and Randall (1994).

Vegetation communities vary with the stability of the shingle, the amount of fine material amongst the shingle, and the hydrological regime. The seaward areas are only sparsely and seasonally vegetated by pioneer species, tolerant of sea spray and annual change. Plants have seeds that are distributed by waves and get nutrients from decaying seaweed and other debris. In the landward areas of the shingle, where conditions are more stable, grassland, heath and scrub communities can develop. Shingle supports a number of species largely confined to this habitat, as well as those also associated with sand dune and saltmarshes (Murdock *et al* 2010).

Species typical of the seaward edge are those which can cope with exposure to salt spray and some degree of burial by sediment, or are annuals colonising each year after winter storms. Perennials include sea kale *Crambe maritima*, sea pea *Lathyrus japonicus*, sea beet *Beta vulgaris*, and sea campion *Silene uniflora*. Annuals include Babington's orache *Atriplex glabriuscula*. The annual vegetation needs the right combination of seed supply, seasonal stability and nutrients to establish. Seed production is essential to maintain its presence, and most species have seeds that can float to enable transport by wave action. Seeds cannot establish if they are buried too deeply. As a result, the location of the vegetation may vary from one year to the next. The plant species that are adapted to the conditions are limited, and there are geographical variations from north to south (JNCC 2007). This community remains highly vulnerable to human disturbance, including trampling from recreational activities (JNCC, 2013).

Away from the tideline, where conditions are more stable, mixed plant communities develop, and over time can form grassland, heath, moss and lichen communities, and even scrub. Some of these communities appear to be specific to shingle, and some are only known from Dungeness. On the parallel ridges of cuspate forelands, patterned vegetation develops, due to the differing particle size and hydrology. A few shingle sites contain natural hollows which develop wetland communities. Where gravel extraction has taken place, some similar wetland vegetation can colonise at the fringes of restored gravel pits. Saline lagoons are often associated with shingle systems, as the sediment allows exchange of sea water,

Shingle structures may support breeding birds, including gulls, waders and terns. Diverse invertebrate communities are found on coastal shingle, with some species restricted to shingle habitats. There are specialised invertebrates found on both vegetated and bare shingle, with some living deep in the matrix where humidity and temperature are suitable for survival.

Potential climate change impacts

Cause	Consequence	Potential impacts
Sea Level Rise	Altered coastal dynamics in long term	■ Changes to the amount of sediment being supplied naturally from offshore sources and removed from shingle beaches and systems, such that loss may exceed supply. This will also be affected by adjacent hard defences that restrict sediment supply from erosion and longshore drift of sediment into shingle systems. This can lead to sediment starvation and breakdown of systems, plus demands for more artificial recycling and hard defences.
Increased storminess and more frequent extreme events	Altered coastal dynamics over short time periods	■ The level of impact will depend on the current degree of natural function. Systems with intervention, e.g. in form of re-shaping the beach crest with bulldozers, will experience the most extreme impact as the natural evolution has been prevented. More natural systems are more resilient, and beach ridges can breach, roll back and develop new morphology. ■ Storms can help create new beach ridges when pulses of sediment are pushed above normal high tide limits. If there is enough sediment then this helps sustain systems and adds new areas for vegetation to colonise.
Increased wave heights	Increased erosion	■ Increased wave action can lead to beach lowering and steepening of the foreshore. ■ Changes in shoreline position and shingle system area is likely to affect mobility, and groundwater levels.
	Human intervention e.g. hard sea defences	■ Hard sea defences can alter coastal dynamics, with loss of sediment exchange and a lowering of beach levels, leading to increased wave energy and more erosion.
Higher annual average temperatures	Longer growing season	■ This may favour some species over others. Species needing cold stratification could decline. Invasive species may become more vigorous and able to spread faster than control measures. Hot dry summers may affect growth patterns of annual species, but this is not well-researched on this habitat.
Drier summers	Drought	■ Periods of drought could result in lower water tables and lead to saline intrusion.
	Warmer weather	■ A rise in visitor numbers could increase the potential risk of trampling and impacts on vegetation and breeding birds.

Adaptation responses

Coastal shingle environments generally require limited management for nature conservation, particularly near the sea. Adaptation should focus on measures that work with the ongoing changes in morphology of the coastal system. Management plans should be developed with understanding of the likely changes. Information about this may be available through a range of sources, including Shoreline Management Plans (SMP). Habitats behind shingle systems may be affected by future change, and plans should consider any habitat replacement needed in advance.

Where there are no existing erosion control measures these should not be introduced. Neither is it desirable for shingle beaches to be re-worked artificially after storm events. The SMP policy will influence decisions on the maintenance or removal of any existing flood risk management measures, but generally conservation sites should work towards a non-intervention policy. Avoid installing any infrastructure or ensure it can be easily adapted and its condition regularly reviewed. An understanding of the geological and geomorphological processes of the site in a wider context will be beneficial, as coastlines rarely function within individual ownership units. Generic guidance for considering adaptation of flood risk management infrastructure is provided in the LWEC report card (Sayers and Dawson 2014)

Visitor pressure should be managed to ensure existing sensitive areas of habitat are avoided, in order to maintain quality and promote natural recolonisation of vegetation.

Some of the potential adaptation options for this habitat are outlined below.

- Restore or maintain habitat in favourable condition and ensure that non-climatic pressures on vegetated shingle areas (such as gravel extraction, coastal defence works, building construction, military use, agriculture, forestry and recreational pressures) are reduced.
- Develop management plans that take account of predicted changes within and beyond the site.
- Consider how activities on adjacent holdings may influence the capacity of the site to adapt, and ensure impacts are minimised. Use an understanding of shingle coastal processes to predict likely changes at a site level and adjust management accordingly. Avoid trying to maintain the current orientation of the beach ridge by artificial methods.
- Assess whether there is adequate space for shingle systems to migrate, and ensure sediment supplies into the site are not compromised.
- Adjust designated site boundaries and interest features as coasts evolve, with the aim of enlarging functional units.
- Together with owners, plan for the relocation of buildings or infrastructure within the site and behind or on shingle systems (as has been done for parts of the MOD ranges at Dungeness).
- Promote better management of shingle systems for flood risk management: avoid frequent artificial re-profiling and move towards wider beaches. This may need careful consideration where assets are present, but there are some good examples of adaptive management, including those contained in the **IPENS Coastal Management Theme Plan** (Natural England 2015).
- Plan for managing a potential increase in visitors, within a wider access strategy, for example by introducing zoning, better information, and wardening of rare species and breeding birds.
- Monitor the spread of potentially invasive species and plan for introducing control measures where necessary.

Relevant Countryside Stewardship options

CT1 Management of coastal sand dunes and vegetated shingle.

This option aims to ensure the appropriate management of existing coastal sand dune and vegetated shingle sites, whether in good condition or needing restoration.

CT2 Creation of coastal sand dunes and vegetated shingle on arable land and improved grassland.

This option aims to create sand dunes and coastal vegetated shingle on arable land or improved grassland locations which were formerly part of sand dune or shingle systems, or are adjacent to such active systems.

Yellow Horned-poppy *Glaucium flavum* on a shingle bank near Cley, North Norfolk. © Natural England/Julian Dowse

Further information and advice

A Guide to the Management and Restoration of Coastal Vegetated Shingle (Natural England, 2003).

The **Report Cards** published by the Marine Climate Change Impacts Partnership provide an overview of the impacts of climate change on marine and coastal environments. More detail is provided in a series of briefing papers, including **Impacts of Climate Change on Coastal Habitats** (Laurence Jones *et al* 2013).

Relevant case study examples

Natural England, **Coastal evolution in Suffolk: an evaluation of geomorphological and habitat change** ENRR647 (2006).

Key evidence documents

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Part 3
Species

Part A - Overview

Part B - Species case studies

Part A Overview

Introduction

This section of the Adaptation Manual provides an introduction to climate change adaptation for species conservation. It also includes case studies identifying practical adaptation options for a range of species, to serve as exemplars to inform wider planning. It should be read in the context of adaptation for habitats (see part 2 of this manual): habitat management is the starting point for species adaptation, but some species may require a more tailored approach to address specific aspects of vulnerability.

Adaptation planning can be approached in four steps:

- Consider the impact climate change will have on the species;
- Determine whether these impacts pose a threat or opportunity, and the level of either;
- Identify and implement appropriate interventions;
- Monitor and review actions.

Monitoring and review form part of an adaptive management cycle, in which lessons are learnt and actions and targets are adjusted on the basis of practical experience.

Different considerations apply at different scales and in different places, depending on, for example, the rarity of a species and the location of a population within its range. Adaptation for the same species may differ in different parts of the country. In this section we approach this through the perspective of national and local planning.

The focus of this section is on responding to the ecological impacts of changes in climate and related physical variables, such as soil water and sea level rise. There are also many indirect impacts resulting from human responses to climate change, which are not dealt with in detail as they are more context-specific and hard to predict.

Great crested newt. © Natural England/Peter Wakely

Impacts of climate change on species

Climate has a range of direct effects on species. Most physiological processes are affected by temperature, for example the rates of respiration and photosynthesis change with temperature. Physiological processes typically increase with temperature up to an optimum, and then decline and eventually break down as temperature rises beyond this point. The effects of climate change on water supply through changing rainfall patterns may be more important than temperature in many cases, but are typically mediated through soil water and catchment hydrology. Even the more direct physiological effects of climatic variables do not always easily translate into ecological effects because of a complex set of interactions with other influences that also need to be taken into account.

The main direct ecological impacts of climate change on species are summarised below. A fuller account can be found in the **Biodiversity Climate Change Impacts Report Card** (Morecroft & Speakman 2015).

Phenology

The timing of spring life cycle events, such as budburst, flowering and egg laying, has advanced in most of the species in which it has been studied. The average advance has been nearly two weeks in the last 30 years, lengthening the growing season. At the other end of the season, some autumnal events such as berry production have also advanced, while others such as leaf fall have been delayed, depending on the environmental triggers for these events. These changes can have a variety of effects on species. An increase in the growing season may benefit some species. However, where different species' life cycle events respond differently to changing environmental cues there may be a breakdown in the synchrony between them. This can have detrimental impacts, for example in reducing food supply, or opportunities for pollination or seed dispersal.

Population dynamics

Most species' populations are, to varying degrees, influenced by effects of weather on mortality and reproduction. The mechanisms vary and include the direct impacts of heat on survival and reduced mortality during warm winters. For well-monitored species such as birds and butterflies, there is evidence of long-term change associated with climatic change (Pearce-Higgins *et al* 2015). The interactions of species with their pathogens, parasites, predators and food sources can be affected by climate. Interactions with land use, land management and other variables also commonly influence species' responses to climate change and extreme events (Oliver *et al* 2015, 2017; Newson *et al* 2014).

Distributional shifts

Many animal species in the UK, especially those with southerly distributions, are colonising new areas to the north of their range, consistent with recorded increases in temperature. In addition, species new to Britain are arriving, and species previously found as migrants are becoming established. Good data are available for a wide range of groups in the UK. There is also evidence of some species moving to higher altitudes. Rates of change in species' range margins differ; though most are not moving fast enough to keep pace with the change in temperature we have seen in recent decades. There are fewer examples of plant populations shifting compared to animals. Being less mobile, plants have tended to respond to changes in climatic conditions by altering the timing of life cycle events and growth.

There is evidence that species with northern or montane ranges, including some birds and butterflies (e.g. the mountain ringlet), are retreating at southern or low-altitude range margins; this is less clear and so far has not happened as fast as range expansion. Changes in distribution can often be modified by sympathetic land management. There is evidence that species preferentially colonise protected conservation sites when spreading north (Thomas *et al* 2012), and also that species persist longer in protected areas at their southern range margins than they do in unprotected areas (Gillingham *et al* 2015).

Community change

Changes in populations, distributions and phenology inevitably lead to changes in ecological communities and in the interactions between species. In the UK, communities of butterflies and birds are changing, with relative increases in the proportion of southern species and decreases in northern species (Oliver *et al* 2017). Another issue is the potential for non-native invasive species or pests and diseases to survive in the UK, where previously they would not have done, or for existing non-native species to spread and start to cause disruption to ecological communities. Some native species may also become more invasive under climate change.

Extreme events

While long-term, gradual changes in patterns of temperature and precipitation play an important role in driving the changes described above, other aspects of climate change can have more immediate and direct impacts on species and their habitats. For example, droughts and floods, which are expected to become more frequent with climate change, can have significant impacts which affect populations and communities for many years, and more prolonged heatwaves are likely increase the frequency and severity of wildfires.

Rising sea levels

Sea level rise is a consequence of climate change and presents a threat to coastal habitats and the species that depend on them. Where natural processes operate, these habitats may, given time, re-establish themselves by moving progressively inland, but this is often prevented by engineered coastal defences. In addition, sea-level rise affects coastal geomorphology, which impacts on inter-tidal habitats and the species they support. For example, increased exposure to wave action can erode productive muddy, estuarine habitats and transform them to less productive sandy habitats. Rising sea levels can also have an adverse impact on freshwater habitats and species close to the coast due to increased rates of saline intrusion and overtopping of coastal defences during storms.

Vulnerability assessment for species

Adaptation planning needs to be based on an assessment of the vulnerability of a species in specific circumstances that goes beyond a generic understanding of impacts.

The assessment of vulnerability is frequently separated into three elements: **exposure**, **sensitivity** and **adaptive capacity**.

Exposure refers to the nature and extent of climate change in the particular situation. The **UK Climate Projections** published by the Met Office provide projections for key climate variables such as temperature and rainfall and for a range of scenarios and time intervals. The RSPB and Natural England often use a 25-year timeframe and scenarios based on a global temperature rise of 2° C compared to pre-industrial levels as a starting point. This provides a practical medium term perspective for developing action, and a milestone towards likely longer term continued climate change.

For many conservation purposes, the detail of climate projections is less important than the direction of travel, approximate magnitude of change and the range of possibilities. It is, however, important to take account of the range of environmental changes that are associated with climate change, including sea level rise, more intense rainfall events, flooding and, potentially, drought and wildfire. Some of these, like sea level rise, can be quantified, but others may need to be assessed qualitatively.

Sensitivity is the extent to which a species is affected by any given change in climate and associated impacts on the physical environment. This can be complex, as different aspects of climate change affect species differently and there are interactions between species and with the physical environment.

Detailed, species-specific studies that demonstrate the mechanisms which cause sensitivity are rare and indicators based on the correlation between observed population and distribution changes are often used. For example, if a species is at the southern edge of its range in the UK and has declined in recent years, this is good circumstantial evidence that it is sensitive to climate even if the precise mechanism is not known.

Adaptive capacity, in this context, is the potential for natural adjustments of species to reduce the impacts from climate change. There are a number of ways in which species can adjust naturally to climate change; for example, dispersal to newly suitable areas, physiological or behavioural responses by individuals, and genetic adaptation to changing conditions. Hence, more mobile species are more likely to disperse to new sites, and species with short generation times are more capable of quick genetic adaptation.

Given the difficulty of carrying out detailed mechanistic studies, approaches to assessing the vulnerability of most species fall into two main types; those based on changes in distribution and abundance (trend based) (Wheatley *et al* 2017), and those based on species characteristics (trait based). One widely used indicator of climate sensitivity is geographic distribution. A species at the northern edge of its distribution in the UK is likely to be limited by temperature and may therefore benefit from a warmer climate, whereas one at its southern range margin is more likely to decline. Climate envelope modelling is one approach to assessing climate sensitivity on the basis of geographic distribution, and is described in detail in section 5. While distribution based approaches are useful, they can be misleading for species which are rare, patchily distributed, or heavily influenced by non-climatic factors. They also fail to take account of adaptive capacity.

Another approach is to look at trends in species' populations over time in relation to weather and climate, if data are available. A Natural England funded project took a combined approach using both projected changes in potential species distribution and trends over time, as the climate has warmed, for over 4000 species (**Pearce-Higgins** *et al* **2015**). This is the most comprehensive model-based study for UK species. Habitat associations may also be useful in assessing climate change sensitivity; for example, species of wet places are likely to be sensitive to drought conditions. Physiological or ecological characteristics of species can also give an indication of sensitivity to different aspects of climate, and in some cases it may be possible to infer useful information for a range of similar species from detailed mechanistic studies of one species.

Uncertainty is present in all assessments of exposure, sensitivity and adaptive capacity. This is not a reason not to take action, but does need to be recognised when undertaking vulnerability assessments and considered in decision making. Uncertainty often cannot be quantified, but it is usually possible to recognise a range of plausible scenarios which can then be taken into account in adaptation planning. For example, it is best to adapt in ways that are robust under a range of possible temperature increases rather than to a single scenario.

A wide range of local and larger scale factors influence species vulnerability in any particular place. Section 5 provides more information about different approaches to assessing vulnerability.

Approaching adaptation for species

Two broad categories of adaptation for species are building resilience to prevent undesirable change and accommodating change where this is inevitable or desirable (for example where a rare species can colonise new sites in a warmer climate) (Morecroft *et al* 2012). Both need to be underpinned by monitoring and the timely review of interventions.

Climate change adaptation needs to be fully integrated with wider conservation planning and delivery if it is to be effective. For example, assessing vulnerability to climate change is a standard part of the management plan review process for National Nature Reserves managed by Natural England (Duffield & Le Bas 2017), and for the RSPB's nature reserves. It is also important that adaptation planning is done within the context of broader objectives determined by local, national and international priorities. These priorities are typically determined by the threat faced by species, the international significance of their populations, their role within ecosystems (for example as keystone species or 'ecosystem engineers'), or their 'iconic' status. An assessment of climate change vulnerability may suggest that it is best to revise objectives, typically to give more attention to species and/or locations where climate adds ecological pressure. Climate change may also influence the setting of different objectives in different locations, which is explored further in the section on adaptation at national scale below.

Adaptation at a national scale

While conservation management usually happens locally, it takes place within a wider geographical context and may form part of programmes that operate at a national scale. The overarching aims of UK and European approaches to conserving threatened species are to prevent extinction, reverse decline, build stronger populations, and reduce threat across the whole range of the species.

Shifting distributions and changing populations of species as a result of climate change may influence conservation prioritisation and strategies to achieve effective results at a national level. As well as a general northward expansion of many animal species, other patterns of spatial change are possible. One of the best documented examples is the 'short stopping' of overwintering wading birds, which remain on the eastern coast of Britain in milder winters rather than moving to the west as they had previously. In such cases, flexibility is required to ensure appropriate objectives for different sites, so that resources are available to support species conservation in new locations. Northward expansion may also require the protection and appropriate management of new sites to ensure that areas are available for colonisation within the new range.

The most important considerations when working at a national scale are summarised below:

Choice of locations for intervention

Climate change may mean that the most suitable places for targeting action for species conservation changes. For increasing numbers of species, conservation efforts may need to shift northwards and take account of changing hydrology and coastal processes. Responses will also differ according to where in a species' range a site is located. At the northern (leading) edge, actions to promote the movement of species through the landscape and encourage the colonisation of new sites may be appropriate, while at the southern (trailing) edge, promoting persistence *in situ* by building resilience or protecting and developing climatic refugia may be more appropriate. At the same time, species new to the UK are arriving and becoming established. These species may be declining in other parts of their range, and their protection in the UK may be essential to prevent global declines.

Changing targets for populations

To compensate for both anticipated and actual losses in parts of the present range where climate change is making conditions less suitable, higher population targets may be needed in other parts where conditions are becoming more suitable. In the short-term, greater investment may be needed in threatened places until populations have built up elsewhere.

Identify refugia

Within parts of the country that are becoming progressively less suitable for a species, there are likely to be some areas where a more favourable local microclimate offers a better chance of the species persisting. A greater focus on identifying and managing these areas as effective climatic refugia may help to maintain a species within a region, even if this is only a short-term measure until longer-term action is possible. Recent research (Suggitt *et al* 2014) has shown that species declining with climate change have tended to survive better in such refugia than the surrounding landscape in recent decades.

Facilitate colonisation of new sites

As well as ensuring species' populations within existing sites are large enough to support dispersal to new areas, action may be needed to assist the colonisation of new sites. This can include improving the connectivity of suitable habitats through the landscape, and proactive management of potentially suitable sites to ensure suitable habitat is available for colonisation.

In some circumstances, species may be slow or unable to colonise new areas, so artificial translocation to new sites may be the only option which allows establishment in a new location. These may include locations within the species' present range where conditions are likely to remain suitable, as well as locations in new areas of climate suitability. This has not been used as a response to climate change by Natural England or the RSPB to date, but may well be in future.

Migratory species

The needs of migratory species can be complex, and conservation efforts may be required at different sites along a species' migratory route. In many cases, this will involve sites in other countries, and international cooperation will be important. Within the UK, the main adaptation response will be to ensure a sufficient number of suitable 'landing sites'. As with resident species, the location of these sites may vary as climate changes.

Ring ouzel. © rspb-images

Adaptation at the local scale

At the local scale, for example on a nature reserve, decisions about managing individual species are made in the context of the wider range of communities and habitats on site. Climate change adaptation is no different in this respect, and adaptation of habitat management is considered in more detail in the Habitat section of the adaptation manual.

Nevertheless, there are circumstances where a more tailored approach to individual species is desired. Figure 1 provides a framework for this, based around building resilience of populations *in situ* or accommodating change.

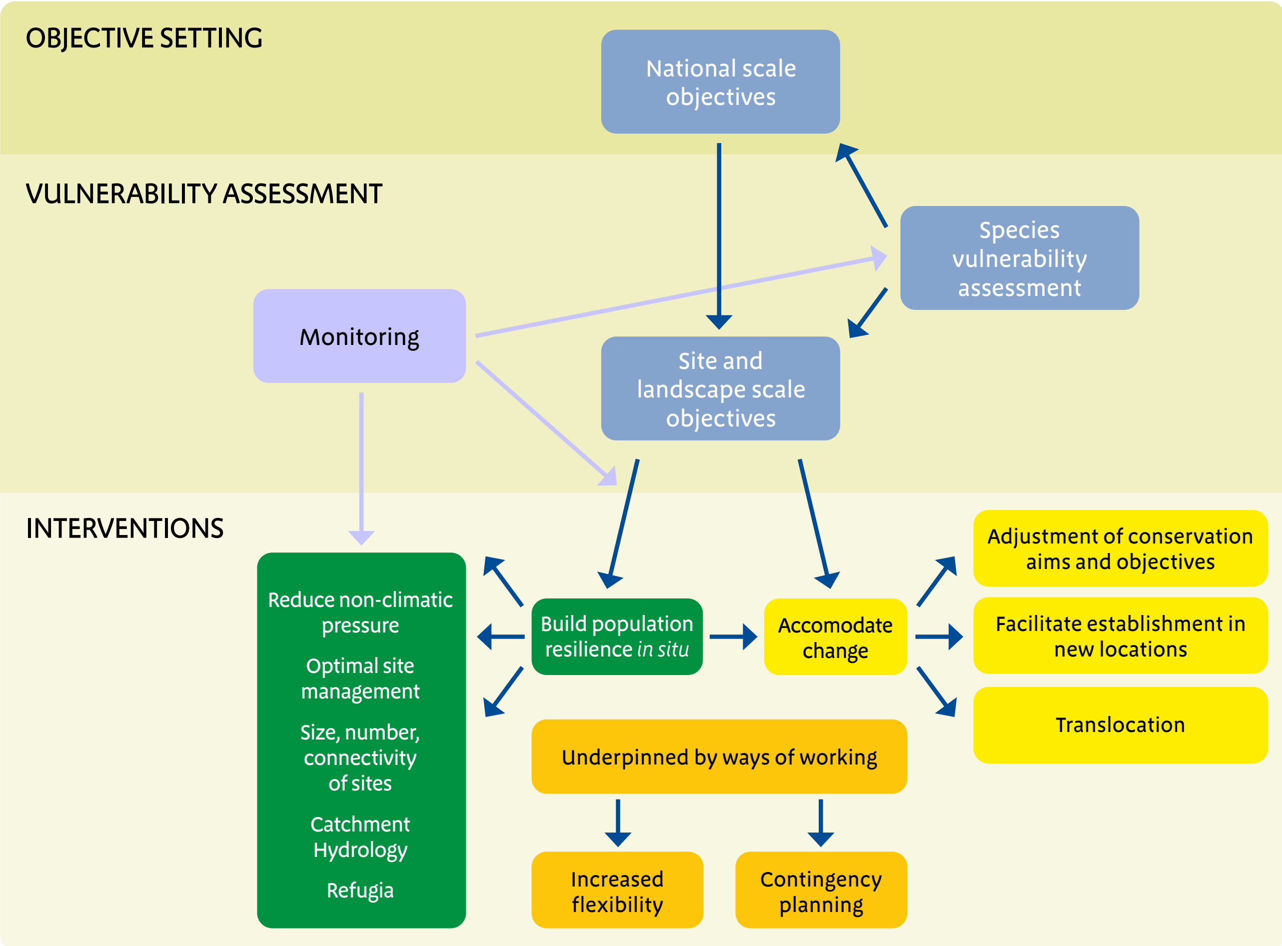

Figure 1: Approach to adaptation for species at the local scale

Building resilience of species populations *in situ* at local scale

Actions that can contribute to maintaining species *in situ* are outlined in Box 1 below.

- Enhance site quality by addressing non-climatic pressures such as inappropriate management, pollution and over-abstraction.
- Increase the size, number and connectivity of habitat patches within the landscape.
- Identify potential local refugia, and target management intervention to increase species populations in these areas.
- Create structural diversity within habitats, which increases the range of microclimates available to species. The Natural England Mosaic Approach sets this out in more detail.
- Control invasive, pest or pathogen species, which are likely to increase with climate change.
- Restore natural hydrological function, for example by blocking artificial drainage or reinstating natural river courses. Where natural hydrology cannot be restored, there may be a case for increasing control through sluices or pumps to ensure an optimal water level in locations of importance for threatened species.
- Manage competitor species which are benefiting from a warmer climate or changed hydrological conditions.
- Adopt more flexible management to respond to within and between year variation in the weather.
- Increase resilience to extreme events and use contingency planning to ensure effective recovery responses.
- For species with limited mobility, such as arctic-alpine plants, consider local translocation to suitable micro-sites, taking account of changing temperature, hydrology and coastal processes.

Box 1: Actions that can contribute to building resilience of species populations *in situ*

Implementing good conservation management under the present climate and reducing other pressures on species at site level is the most basic approach to building resilient populations. Anything which increases population size increases both the chances of a population surviving a period of adverse weather and of individuals dispersing and colonising new locations locally.

Although optimising site management and reducing pressures on the site is an essential starting point, it will not be sufficient for all species, and what constitutes optimal management will itself change as the climate changes. The impact of climate change on species is set within the context of the habitats and systems where they occur. For example, in grassland, changes in the growth rate of different species may lead to changes in their competitive ability, leading to the loss of target species. In this case, grazing or cutting regimes could be adjusted to counter this change. Other potential changes to management include managing competitor, pest or pathogen species that are likely to benefit from a warmer climate or changing hydrological conditions. Another approach would be creating more structural diversity within the landscape, which increases the range of microclimates available to species. For example, changing the height of the sward or increasing the amount of scrub and trees to create shade could be used to counter increasing temperature and the risk of drought. Natural England's Mosaic Approach sets this out in more detail. Planting trees beside water courses can also lower water temperatures and enable temperature sensitive fish species such as salmon and trout to survive; the **Keeping Rivers Cool** manual provides more information on this.

Most conservation sites in the UK are relatively small and influenced by the surrounding landscape and the catchment in which they occur. Increasing the size, number and connectivity of habitat patches can build larger, more resilient poplulations. Larger sites tend to support larger populations, and are also less influenced by surrounding land which may be unsuitable for species. For example, true woodland specialist species require deeply shaded, frequently damp, conditions which only develop well away (e.g. 100m) from the woodland edge. Where small sites can support species, the extent to which a large number of sites within a landscape can increase resilience will depend on specific circumstances, particularly the mobility of species and the degree of connectivity (including proximilty) between sites.

Where mobile species form metapopulations across a number of sites, there may be considerable benefit if new sites can be created. Species with low mobility at all stages in their life cycle are much less likely to benefit due to their inability to reach new sites. Connectivity can be increased through new sites, but also by connecting habitat such as hedgerows and corridors. 'Softening the matrix' – ensuring the the intervening land between habitat patches can allow species to pass through easily – can also help. For example pollen and nectar mixes that provide food facilitate movement between patches for some species, even if they are not suitable habitat for breeding. It is important to note that connectivity is not a panacea for all species and also carries risks. In particular invasive species, pests and pathogens may be enabled to spread by increasing connectivity.

Hydrology is a key determinant of habitat quality for wetland and aquatic species. It is also liable to change as rainfall patterns change and warmer conditions lead to higher evapo-transpiration rates. Changes in the hydrology of sites are a significant threat to many species. In these cases, the restoration of natural hydrological function may be the best way to facilitate adaptation, for example by blocking artificial drainage or reinstating a natural river course. However, many sites are small and reliant on structures and management for their continued existence, so in the short- to medium-term, where natural hydrology cannot be restored, there may be a case for increasing control through sluices or pumps to ensure optimal water levels in locations important for threatened species.

The concept of refugia (see above) is relevant at local as well as national scales. Even within a site there are often areas which are locally colder (such as higher altitudes and north facing slopes), more likely to retain water during dry summers, or less prone to flooding or erosion. Well managed refugia can both help populations to survive on a site and help to build strong populations that are more able to disperse to more climatically suitable areas.

Accommodating change at local scale

Some changes in species are inevitable with climate change, regardless of how resilient a system is. Species distributions have already changed substantially for some more mobile species (Morecroft & Speakman 2015), coastlines have changed with rising sea levels, and habitats may change as the balance between different species shifts. Conservation management may cease to be effective it fails to take account of such changes.

Adjust conservation aims and objectives

There is clear evidence that many animal species are colonising locations to the north of their previous range in the UK (Mason *et al* 2015), and that SSSIs are often the first sites to be colonised (Thomas *et al* 2012). Where a species of conservation interest colonises an area, the most important response is to recognise that it is a new interest feature on the site and to start to factor its presence into management planning and the assessment of site condition. The balance of species within communities is also changing. It is therefore important to monitor the status of species and communities and to review management plans and indicators of favourable condition on sites. Modelled projections of changes in species populations due to climate change can help to highlight those species for which particular attention may be necessary. However, given the range of factors which interact with climate change and the potential to build population resilience *in situ*, it would be premature to remove a threatened species from site management objectives while it continues to survive there. Similarly, there is no reason to accept a decline as inevitable until interventions to build resilience have been attempted.

Facilitate the colonisation and establishment of species at newly suitable locations

Although many species are colonising new climatically suitable areas without human intervention, this generally lags behind the speed of climate change, and a large number of other species have limited dispersal capacity. As climate change continues, a proactive approach may be increasingly beneficial or necessary for some species. This is a national and international issue, but it has important local implications.

There are three main ways in which colonisation of a new site may be facilitated:

1. Where a species can reach a new site but cannot establish a viable population, management to create suitable conditions may be necessary. This may involve additional habitat creation, improving the quality of the site (e.g. through sward enhancement), or modifying site management for the specific requirements of the incoming species.

2. Where a species is mobile and has the capacity to disperse, it may benefit from developing an ecological network in which species can move between sites. Physical connection, proximity, and the characteristics of the intervening land can all increase the chances of colonisation and establishment (Lawton *et al* 2010). Landscape scale conservation initiatives such as **Futurescapes** and **Living Landscapes** are useful approaches for developing ecological networks. The Nature Recovery Network also aims to create and restore ecosystems on a large scale in order to repair our national network of habitats. Please see Natural England's **Nature Networks Handbook** (Crick *et al* 2020) for more details on how to design a multifunctional ecological network. Building up populations on existing sites is also important, to ensure there are sufficient individuals with the potential to disperse and colonise new sites.

3. Where a species has limited mobility, *translocation* may be considered. Translocation involves the removal of individuals of a species from one site and transporting them to other sites, to establish new populations or augment existing threatened populations. Many habitat creation and restoration activities might be regarded as translocation, including those used to revert arable land to grassland, stabilise the surface of eroding bog, and tree planting to create new woodland, as species are artifically established outside their current locations. Translocation in the context of climate change is likely to focus in the first instance on introducing species to suitable sites on or just beyond their present northern range margins, rather than moving species hundreds of kilometres north. The impact on existing populations should be minimised by transplanting propagules or raising individuals in controlled conditions *ex situ*.

   The need for consent should be considered in all cases and permission sought if necessary. Natural England local staff can provide advice on specific situations. Outside habitat creation and restoration schemes, translocation is not currently used widely in UK conservation as a response to climate change. It may, however, be preferable to increasing connectivity in some circumstances, for example:

- For species with poor dispersal ability, where simply increasing connectivity is unlikely to be sufficient.
- Where suitable habitat cannot be easily found or created in the immediate vicinity of present sites. Many species are habitat specialists or require associations with other species, which prevents them taking advantage of newly created habitat in the wider agricultural environment.
- Where lack of opportunity or resources for improving connectivity means that physically moving species may be a more practical option.

Ways of working

The adaptation responses outlined above will often require changes to the way management interventions are planned and delivered. Key requirements are flexibility and contingency planning as well as normal management planning.

Flexibility

Climate change is already leading to increased variability in weather, both within seasons and between years. This means that greater flexibility needs to be built into long-term planning and practical management. For example, it may be more necessary to alter grazing intensity, stock movements and dates of operations.

Contingency planning

The frequency of extreme events such as drought, heatwaves and flooding is increasing. Contingency planning to ensure effective prevention and recovery responses following such events is likely to be a key action for species in areas at risk. Examples include wildfire management plans on heathland, and installing suitable sluices on coastal wetlands susceptible to saline incursion.

Supplementary information on vulnerability assessment

This section expands on the approaches to assessing vulnerability discussed in section 3.

A large amount of academic study has gone into developing methods to assess species vulnerability to climate change. Pacifici *et al* (2015) provide a review of the main approaches and issues. They recognise three broad approaches to vulnerability assessment: mechanistic, correlative, and trait-based.

Mechanistic approaches draw on a detailed understanding of the physiological and/or population responses of a species to climate. This can give a more accurate assessment of species vulnerability to climate change, although the level of understanding required is not available for the vast majority of species. Even if a single species is well known, it also requires a knowledge of key interactions with other species and the factors that affect them. There are a small number of British species where sufficient in-depth knowledge is available to help guide management. Some of these are presented in the case studies. These exemplar species can also help to identify mechanisms of vulnerability and adaptation that have a wider application.

Correlative approaches infer climate change sensitivity from current correlations between climate and species. Climate envelope modelling is the most common example, where a relationship between a species' distribution and climate is inferred from its current distribution, and used to model future potential 'climate space'. Another example would be to correlate trends in population abundance over time with changes in climatic variables.

Trait-based approaches are based on the concept that key characteristics of species can be indicators of the likely vulnerabilities of a wide range of species to climate change. They have the potential to provide a way of screening species to identify those that are most at risk, without detailed and reliable information on distribution, population change or specific mechanisms.

Wheatley *et al* (2017) reviewed a range of different vulnerability assessment methodologies for species and concluded, for British bird and butterfly species, that those based on traits alone failed to predict those species which changed most during recent climate change. In contrast, approaches that used correlative approaches including an assessment of previous trends in species, did have some success in predicting species vulnerability. This included the methodology of the Natural England funded project which assessed over 4000 UK species (Pearce-Higgins *et al* 2017, 2015). It should however be noted that even in this project, there was relatively low confidence in the projections for many species beyond birds and butterflies, so care and judgement are needed, using a wide range of different information.

Climate envelope models. The relationship between a species' distribution and climate can be modelled using climate envelope models, which quantify the relationship between distribution and climatic variables using a range of mathematical techniques. These relationships can then be used to project where suitable climate is likely to be found in future on the basis of climate change scenarios. The most up to date and comprehensive assessment using a climate envelope approach in the UK, referred to above, took account of not just modelled projections of species range change but also changing distributions (Pearce-Higgins *et al* 2015, 2017). Species maps derived from this project are available via the **Natural England Open Data Geoportal** and are used to illustrate the case studies presented at the end of this section of the manual. Earlier projects included **MONARCH** (Modelling

Natural Resource Responses to Climate Change), **BRANCH** (Biodiversity Requires Adaptation in Northwest Europe under a CHanging climate) (BRANCH Partnership, 2007, maps available **here**) and an atlas showing the impact of climate change on the distribution of Europe's breeding birds (Huntley *et al* 2007).

Climate envelope modelling has proved a valuable guide to species sensitivity to climate change. It is useful for identifying where adaptation action may be necessary, for example in places where a species is likely to be at risk or to have an opportunity to colonise. Limitations of this modelling, which need to be understood when developing adaptation action, include the following:

- If current distributions are determined largely by factors other than climate, such as soil conditions associated with a particular local geology, or human activities, including land management and persecution, the relationship between present day distribution and climate will be weak and of limited value in projecting future change. In the cases of rare or localised species, it may often simply not be possible to derive any meaningful relationship between distribution and climate (Pearce- Higgins *et al* (2017) found this was the case for 10% of the species studied).
- Climate change may result in climatic conditions for which there is no present day analogue, and therefore projections based on present climate will be unreliable.
- Distribution data available for modelling may not cover the whole geographical range of a species (for example if only UK or European distribution data are available for a species that has a wider global distribution), and so models will not give a full representation of the climate space that can be occupied.
- Climate and distribution are typically mapped at a large scale (tens of kilometres). The actual distribution of species may, in practice, be determined at a much smaller scale according to local microclimatic conditions. For example, a mountain top species may be restricted to the coolest parts of a grid square, whereas the climate value for that square reflects an average.
- Distribution maps for some species may not be accurate. Britain has better datasets than most other countries, but there are still gaps in the distribution record for more isolated areas and for harder to identify and less charismatic groups of species.
- The presence of refugia, where local climate variations and microclimates provide conditions in which a species can survive locally, but which gridded climate data are too coarse to pick up.
- Projections of future climate change are not forecasts and include inherent uncertainties about future emissions and the sensitivity of the climate systems They also cannot take account of the full range of weather conditions contained within the climate projections, such as rare events to which species may be vulnerable.

Climate envelope models indicate where climate conditions may be suitable. They do not take account of other factors, such as whether a species can reach a new potential location, or whether other requirements such as habitat or food supply will be available there. Nevertheless, climate envelope model outputs may prove useful in helping to identify where adaptation measures may make a difference.

Trait-based approaches

Particular ecological traits can be identified which may indicate a species' likely vulnerability to climate change, or potential opportunities. The term 'trait' can cover a wide range of attributes, ranging from a species' distribution to aspects of physiology and broader functional types. In most cases, a combination of traits is likely to be more valuable than any single one.

The following are potentially useful traits for which information is available in the UK.

Distribution-based traits. In the UK, the distribution of most species is known to some extent. In general, southern species, with their northern range margins within the UK, will tend to spread northwards if they are not limited by dispersal capacity or habitat fragmentation and availability. Conversely, northern species with a southern range margin in the UK are at risk of range contraction, with a loss of their southern outposts. This potential change in range may be assessed using climate envelope modelling (see above). However, it can also be used to derive indicators of a species' climatic requirements (e.g. mean temperature it occurs at) which may in turn indicate where it will be at risk and where it may have opportunities to colonise. Some indices are available to reflect this, including mean climate statistics for the UK, for a range of plant species in the **Plantatt** dataset. Species distribution data for the UK are also available on the **National Biodiversity Network Atlas** website.

Mobility. The more mobile a species is, the better it is likely to be able to change distribution to track suitable climate. Mobile species are also able to disperse locally to places where they may be better able to survive adverse weather conditions, for example, wet areas during a drought, or cooler, north facing areas during periods of high temperatures. Migratory species, in particular, are often adapted to be able to search out new areas each year, especially if they utilise relatively ephemeral habitats. However, some migratory individuals become relatively fixed in their migratory patterns after their first migration, so changes in location may only occur with each new generation.

Reproduction/life cycle traits. Species with high reproductive rates and short generation times, described as r-selected species, can produce more offspring, increasing the potential for dispersal to new sites, and also have the potential for more rapid genetic adaptation to changing conditions. Conversely, K-selected species, which are typically long-lived and slow reproducing, may be better able to survive *in situ*, at least in the short term, but less able to adapt to changing conditions.

Plant CSR strategies. The Competitor – Stress tolerator – Ruderal scheme for categorising plants (Grime, 1974) is a widely used approach to functional types. Competitor species can grow quickly when conditions are favourable and resources available; stress tolerant species are slow growing and adapted to survive low levels of resources; and ruderal species reproduce quickly and exploit temporary habitat availability. Intermediate types can be recognised along a spectrum between the extremes. Different aspects of climate change may favour one type or another, so, for example, species with stress tolerant characteristics may be better able to survive a drought; ruderals to colonise bare patches of ground after a drought, flood or wild fire, and competitors to benefit from increasing mean temperatures and a longer growing season.

Specialism/generalism. The greater the level of specialism, the greater the level of reliance on a narrow range of niches, such as microclimate or other species. This, in turn, means that the influence of climate change may act through its impact on other ecosystem components upon which a species relies, as well as directly on the species. The more generalist a species, the more likely it is to be able to exploit multiple niches and habitats, which may reduce the impact of climate change, or enable it to benefit from new opportunities.

Modelling changes in tree growth

An analogous approach to climate envelope modelling has been developed for predicting the growth of trees in the **Ecological Site Classification Decisions Support System** developed by Forest Research. This models the future 'suitability' of woodland types and individual species based on correlations between measured growth rates of different tree species with physical variables, including climatic, at sites throughout the UK. For conservation purposes, it is worth noting that a species may still survive at a site even if it produces a poor timber yield.

Modelling changes in species populations

Modelling of changes in species populations in relation to weather conditions has been carried out for some species, particularly through the **BICCO-Net project** (Pearce-Higgins *et al* 2015). It is not widely available as a tool for conservation practitioners at the present time but offers potential for future development. Qualitative information about the impacts of periods of contrasting weather can also be useful in conservation management.

Ecological studies

Experiments, ecophysiology and auto-ecological studies can all provide invaluable information on the responses of species to climate change, although this detailed information is only available for a small proportion of UK species. Natural England's specialist staff can provide advice, as may other local experts, and both Natural England's and the RSPB's species priorities and recovery programmes are underpinned by good ecological knowledge. Some nature conservation sites, including a number of National Nature Reserves, have been used for research over a long period of time and this may help to inform decision making.

Factors modifying species vulnerability to climate change

A variety of other environmental factors, including habitat fragmentation and degradation, can exacerbate vulnerability to climate change, by increasing exposure to new climatic conditions or reducing the adaptive capacity of species. Possible factors that could increase the vulnerability to climate change, and which should form part of a vulnerability assessment, are outlined in the table below.

Table 2: Environmental factors increasing the vulnerability of species to climate change approach to adaptation for species at the local scale

Environmental factor	Reason
Isolated habitats	Isolated populations are less able to colonise new sites with more favourable climate or microclimate.
Small site size	Small sites generally support small populations, which are more vulnerable to extreme events and disease etc. Small sites are also generally less heterogeneous and have less microclimatic variation, and are therefore more prone to damage from extreme events.
Poor site condition	Sites in poor condition generally support smaller populations, and are therefore more vulnerable to extreme events.
Topgraphic homogeneity	A more homogeneous landscape will generally have less variation in microclimate, and therefore fewer opportunities for species to survive in local refugia.
Non-climatic pressures	If populations are under pressure from non-climatic factors such as pollution or competition from invasive species, their ability to withstand climate change may be compromised.

In some instances, environmental factors may locally reduce the vulnerability for some species. These are illustrated in table 3.

Table 3: Examples of environmental factors which may locally reduce vulnerability of species to climate change

Environmental factor	Reason
Locally cool microclimates, such as north facing slopes and high altitudes	These may act as refugia for some species.
Ground water fed wetlands and water courses	These may buffer water supply against fluctuating rainfall and a trend towards drier summers with wetter winters.
Topographic heterogeneity	More heterogeneous landscapes will generally have a greater range of available microclimatic niches.
Proximity to the coast	The maritime influence helps to moderate temperature extremes (although it may cause other vulnerabilities e.g. saline intrusion, wave action).
Large sites	Large sites generally support larger and more resilient populations, provide a wider range of environmental conditions, and usually exhibit fewer edge effects.

Finally, various forms of human activity can influence the vulnerability of a species, both locally and across landscapes, and so need to be considered as part of species vulnerability assessments. Some examples are given in table 4.

Table 4: Examples of anthropogenic factors that may influence the vulnerability of species to climate change

Environmental factor	Reason
Coastal defences	Coastal defences have the ability to protect some coastal and wetland sites. However, they can also prevent natural coastal processes and roll-back, and increase the vulnerability of sites to sea level rise and wave action.
Water control and abstraction	Control over hydrology has the potential to reduce the impact of changes in rainfall and extreme events. Abstraction has the potential to exacerbate problems of limited water availability.
Management practice	Flexibility in land management, including changes to the timing and nature of farming operations, can be an effective response to changing weather patterns. Conversely, a more rigid approach, for example fixed dates for hedge or hay cutting, that does not take into account seasonal variations in the timing of natural events such as nesting or seeding, could make some species more vulnerable.

In conclusion, there is a range of approaches to assessing the vulnerability of species to climate change, and many environmental and management variables that may increase or reduce that vulnerability. There is no single 'right' approach to vulnerability assessment – the specific context will determine what is appropriate and practical. Decisions will inevitably need to be made in the face of incomplete knowledge, but an adaptive management approach in which the effectiveness of management actions is monitored, reviewed and if necessary adjusted is a good approach and will help to ensure that lessons are learnt from experience.

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Part B Species case studies

Introduction to species case studies

The preceding sections outlined the issues to be taken into account when considering appropriate adaptation actions. These include an assessment of the impacts of climate change in order to determine the threat or opportunity that it may pose. Consideration of other pressures and the effectiveness of different forms of intervention are then required to identify the range of potential actions.

The following species case studies provide examples of how these steps have been applied to a range of species that are sensitive to climate change. Each case study uses the same format to describe the general ecology and distribution of the species and the likely impacts of climate change, together with an assessment of the confidence level in these impacts. This is followed by a range of potential adaptation options that may be appropriate in individual locations. Examples of where these actions are being implemented and links to the wider literature are also provided.

The species selected for case studies are all species of conservation interest for which the evidence suggests that climate change is likely to be an important conservation issue. They have been selected to represent a variety of species groups, and to illustrate a range of approaches to adaptation. It is envisaged that the list of case studies will be added to over time.

Each case study is structured as follows:

1 Summary table

This table summarises the threats and opportunities that climate change presents to that species and the ability of interventions to address them. Each element is scored according to a simple Red – Amber – Green (RAG) assessment. Where climate change will benefit a species, the sensitivity box is coloured green and the text reads *Potential Benefit*.

Climate change sensitivity is determined from a range of sources. The primary source is the species risks and opportunities report basic and migratory bird assessment tables (Pearce-Higgins *et al* 2015), while for butterflies, the assessment in Thomas *et al* (2011) has been used. For species not covered in these analyses, a review of other published evidence has been used. Where climate change will benefit a species, the sensitivity box is coloured green and the text reads *Potential Benefit*.

Non-climatic threats. This assessment considers the severity of non-climatic pressures affecting the species, including land use change, pollution, and habitat fragmentation. The judgement is derived from a literature appraisal. The severity of non-climatic pressures influences the capacity of the species to respond to climate change.

Ability to manage. This assessment considers the ability of management to address the adverse impacts of climate change, such as altering grazing regimes to address changes to growth characteristics or competition, or controlling water levels to balance increased water deficit. The rating relates to how effective *in-situ* management is likely to be in addressing the threats posed by climate change. **Please note** - the RAG status in this assessment works in the opposite way to the above assessments, i.e. a high ability to manage is coloured green and a low ability is coloured red.

Vulnerability. The overall vulnerability assessment for the species is based on consideration of the results of the three other boxes.

The table below brings together these assessments for all the species in this section:

Species	Climate change sensitivity	Non climatic threats	Ability to Manage	Vulnerability
Adonis blue	Potential Benefit	Medium	High	Low
Alpine lady's-mantle	High	Low	Low	High
Atlantic salmon	High	High	Medium	High
Baltic sphagnum (*Sphagnum balticum*)	High	Medium	Medium	High
Beech	Medium (high for drought)	Low	Medium	Medium
Bilberry	Medium	Medium	Medium	Medium
Bluebell	High	Medium	Medium	Medium
Common green grasshopper	High	Medium	Medium	Medium
Curlew	Medium	High	Medium	High
Dartford warbler	Potential Benefit	Medium	Medium	Low
Forester	Medium	High	Medium	Medium
Golden plover (breeding)	High	High	High	Medium
Golden plover (wintering)	Potential Benefit	Low	Low	Low
Great crested newt	Medium	High	High	Medium
Keeled skimmer	High	Medium	Medium	Medium
Large heath	High	High	Medium	High
Little tern	High	High	Medium	High
Mountain bumblebee	High	Medium	Low	High
Mountain ringlet	High	Low	Low	High
Northern brown argus	High	Medium	Medium	High
Ring ouzel	High	Medium	Medium	High
Silver spotted skipper	Potential Benefit	Medium	High	Low
Small red damselfly	High	High	Medium	High
Tree lungwort	High	High	Medium	High
Twite	High	High	Medium	High
White faced darter	High	Medium	Medium	High
Whitefish, vendace and Arctic charr	High	High	Low	High

2 Summary

The summary provides a brief overview of the key facts from the following sections.

3 Description

This provides a general description of the species.

4 Ecology and Distribution

This section describes the general ecology and UK distribution of the species, focusing on those aspects most relevant to climate change; for example, particular aspects of its ecology that may make a species vulnerable to climate change, such as a preference for cool, shady microclimates, or areas with higher water tables.

The species distribution is shown on a map derived from a range of recording schemes. For example, For bird species, maps from the BTO Atlas of Breeding and Wintering Birds of Britain and Ireland (Balmer *et al* 2013) have been used. This is shown for two time periods, pre and post 1990, to show its historic distribution and any recent change. Changes to the distribution can be used to infer climate change sensitivity. These maps show all 10km² grid squares for which a species was recorded during each of the time periods. The post-1990 record does not necessarily represent the current distribution.

White faced darter. © rspb-images.com

5 Climate Change Impacts

This section describes how the species is expected to be affected by climate change.

The initial table provides a RAG assessment of how confident we are that changes in the *Distribution* of the species are primarily due to climate change, and our understanding of the *Mechanism* behind observed changes; both of which are important considerations when identifying appropriate interventions.

The table below brings together these assessments for all the species in this section:

Species	Distribution change	Mechanism
Adonis blue	Medium confidence	High confidence
Alpine lady's-mantle	High confidence	Medium confidence
Atlantic salmon	NA	NA
Baltic sphagnum (*Sphagnum balticum*)	High confidence	Low confidence
Beech	High confidence	High confidence
Bilberry	Medium confidence	Medium confidence
Bluebell	Medium confidence	Low confidence
Common green grasshopper	Low confidence	Low confidence
Curlew	High confidence	Low confidence
Dartford warbler	High confidence	High confidence
Forester	Low confidence	Low confidence
Golden plover (breeding)	High confidence	High confidence
Golden plover (wintering)	High confidence	Medium confidence
Great crested newt	Low confidence	Medium confidence
Keeled skimmer	Medium confidence	Medium confidence
Large heath	Medium confidence	Low confidence
Little tern	High confidence	Medium confidence
Mountain bumblebee	Medium confidence	Low confidence
Mountain ringlet	High confidence	Low confidence
Northern brown argus	High confidence	Low confidence
Ring ouzel	High confidence	Low confidence
Silver spotted skipper	High confidence	High confidence
Small red damselfly	Low confidence	Low confidence
Tree lungwort	High confidence	Medium confidence
Twite	High confidence	Low confidence
White faced darter	High confidence	Low confidence
Whitefish, vendace and Arctic charr	NA	NA

The text describes the observed and predicted impacts of climate change on the species, evidenced from the literature, and covers likely distribution and population changes, and other climate change threats or opportunities. Where there is evidence about the mechanism responsible for change, this is presented.

For most species, maps showing the projected change in the suitability of the climate under a 2°C warming scenario are provided. These are derived from **research** undertaken for Natural England in 2015 (Pearce-Higgins *et al* 2015) and are based on modelled data. Where maps are not included, this is because either the species concerned was not covered by the original research, or because there is low confidence in the model for that species. This is most likely to occur for very rare species with a highly restricted distribution, species whose current distribution consists of remnant, disjunct populations, and species whose UK distribution reflects only a very small portion of its true climatic range.

These maps are created using statistical models which describe the probability that a species will be found in a 10km grid square, based on its current distribution and its relationship to a number of climatic variables. These can be used to model the suitability of grid squares for a species under possible future climates when climate change projections are taken into account. Please note that the maps show only climate suitability and do not take any account of the other factors that might influence a species' distribution.

More information on climate envelope modelling and the use of climate suitability maps is provided in section 3 of this chapter.

6 Adaptation options

This section outlines a range of potential adaptation options for that species, based on an understanding of the species' ecology, its vulnerability to climate change and other pressures, and the likely effectiveness of management interventions. Options include measures to promote ecological resilience and accommodate change, as well as changes to ways of working, including greater flexibility, contingency planning and adaptive management. Where there are gaps in our knowledge, areas for further research and development are suggested.

The options represent a range of actions likely to be effective in promoting the conservation of the species in the face of climate change. They need to be interpreted in the context of local conditions to determine which actions are likely to be most effective and relevant for a particular situation. This consideration needs to take account of the specific local threats, the availability of management options, and the position of that locality within the species' range.

7 Relevant Countryside Stewardship options

Agri-environment schemes are an important mechanism for supporting species adaptation. This section outlines the most relevant options under the Countryside Stewardship scheme.

8 Case studies

Where available, links are provided to relevant case studies that illustrate examples of practical adaptation.

9 References and further reading

This lists the main reports, journal papers, and other publications that have helped inform the species account. Where possible, web links have been provided.

Adonis blue *Polyommatus bellargus*
© Natural England/Peter Wakely

Adonis blue *Polyommatus bellargus* L.

Climate Change Sensitivity:	POTENTIAL BENEFIT	Ability to Manage:	HIGH
Non climatic threats:	MEDIUM	Vulnerability:	LOW

Summary

Summer warming is likely to benefit the Adonis blue, which is known to require hot microclimates for egg laying and larval development. The role of management in creating these conditions is well established. Grazing regimes that deliver short swards are likely to be the most effective intervention, although extreme summer heat and drought may have an adverse impact on the species, meaning that more heterogeneous swards including isolated scrub should increasingly be the objective.

Description

The upper wings of the male are a brilliant sky blue or turquoise colour, with a fine black line round the edge and a white margin. The female is chocolate brown with a few blue scales near the base of the wings, and with orange spots bordered by blue scales around the edge of the hind wing. Both sexes have distinctive black lines that enter or cross the white fringes of the wings. The underside is brownish grey with black and orange spots. The wingspan of both sexes is about 3 cm. The caterpillar is green with short, yellow stripes.

Ecology and distribution

Within the UK, the Adonis blue is restricted to chalk and limestone grassland in southern England. It has two generations in the UK, with the offspring of the second adult generation over-wintering as larvae. Its sole larval host plant is horseshoe vetch *Hippocrepis comosa*.

Eggs are laid singly under young, unshaded horseshoe vetch leaves in May/June and August/September. The Adonis blue overwinters as a caterpillar. In April/May and July/August the caterpillar forms into a chrysalis, which is then taken and buried by ants (which 'milk' the pupa for its secretions), so protecting it from predators.

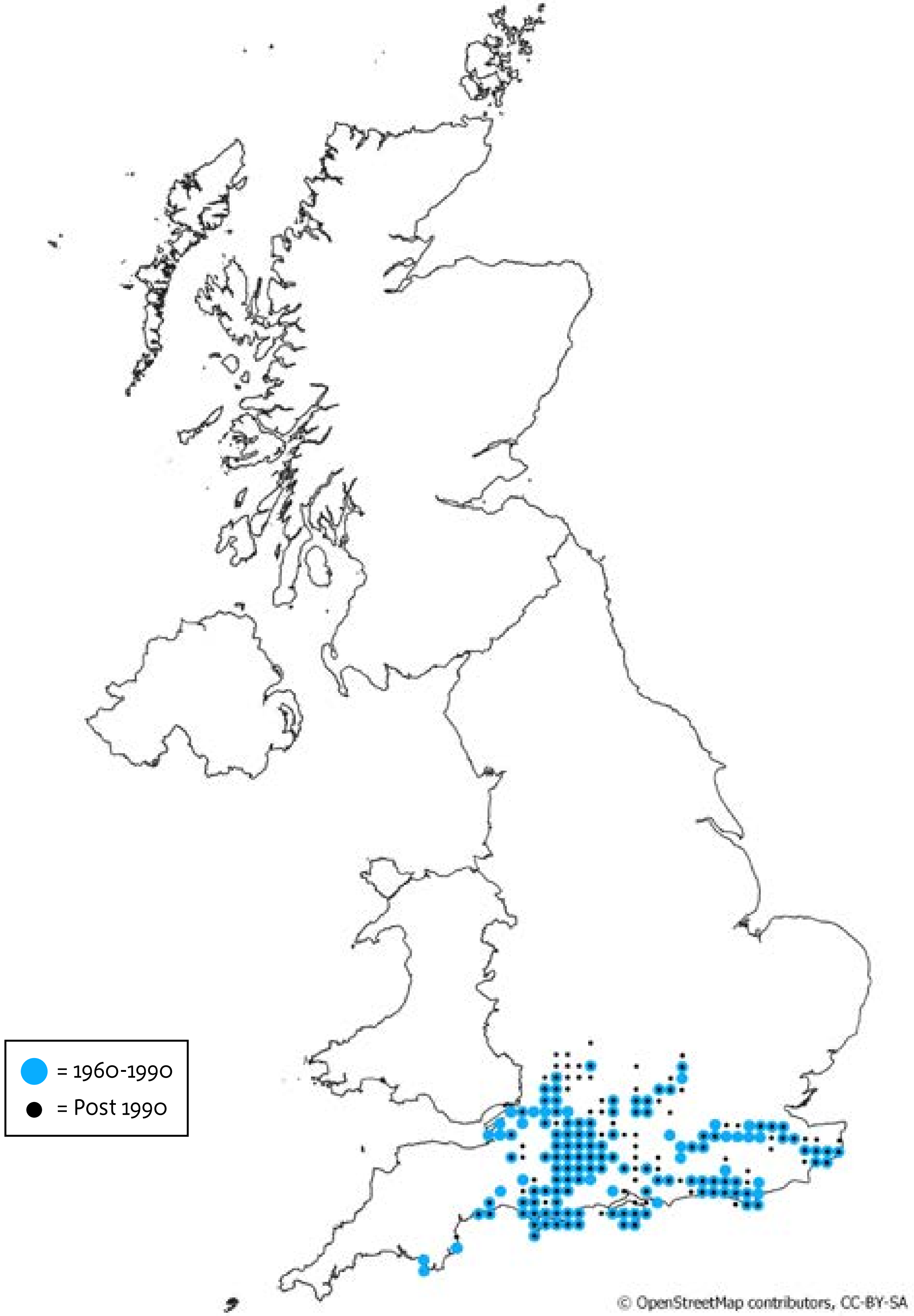
The two generations exhibit different requirements for egg laying and larval development. The first generation lay on horseshoe vetch growing in up to 7cm tall swards, while the second generation autumn/spring-feeding larvae are confined to short turf less than 3cm tall, in sheltered depressions. These microhabitat constraints ensure a warm microclimate but also impose an annual population bottleneck, as there will be fewer plants suitable for oviposition for the second generation (Roy and Thomas 2003).

Historically, the butterfly was recorded in chalk areas over much of southern Britain (Bourn & Warren 1998), but in the second half of the 20th Century it underwent a dramatic decline (Thomas 1983). Between 1950 and the 1980s, 70% of Adonis blue colonies in the UK had become extinct and its range had retracted by 42% (Thomas 1983; Warren *et al* 1997). The cause of this decline was the loss of short-turfed unimproved grassland, largely due to agricultural intensification and the abandonment of extensive grazing, followed by the loss of rabbit populations due to myxomatosis.

Conservation intervention and the recovery of rabbit populations has significantly reduced the height of the sward in many chalk downland sites in the last decades (O'Connor, Hails & Thomas 2014), resulting in warmer microclimates at the host plant level. This has reversed the butterfly's decline (Fox *et al* 2007, O'Connor, Hails & Thomas 2014). Climate change driven warmer summers are also thought to be contributing. Site quality has been shown to be more important than proximity to neighbouring sites in ensuring the persistence of the butterfly (Thomas *et al* 2001), and genetic studies indicate that there is an element of dispersal at distances considerably greater than field observations suggest (Harper, Maclean & Goulson 2003). However, field observations suggest that the butterfly has poor dispersal ability (Thomas 1983) and many former sites remain un-colonised, irrespective of their current condition.

Butterfly Conservation's presence records for Adonis Blue over 2 timeslices, 1960-1990 and post 1990, are shown on the map below (10km grid scale).

Presence of Adonis Blue records, 10km².
Source: Butterfly Conservation: Butterflies for the New Millennium.



Confidence in climate change impacts[13]

Distribution change: **MEDIUM CONFIDENCE** Mechanism: **HIGH CONFIDENCE**

The Adonis blue requires a warm microclimate to complete its life cycle. The recent changes in populations and distribution appear to have been largely driven by changes in the management of sward height (O'Connor, Hails & Thomas 2014). Climate change driven summer warming is likely to benefit to the species.

Egg-laying females in the first generation have been shown to avoid the hottest locations, laying in taller, less sheltered turf (Roy & Thomas 2003), suggesting that extreme summer temperatures may have an adverse impact if the sward is uniformly short. The butterfly has also been shown to be vulnerable to drought, due to the impact on its host plant (Thomas 1983), suggesting that summer drying could adversely affect the butterfly.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

Managing sward height to produce a favourable microclimate provides a clear mechanism to support the recovery of the species. The provision of warm microhabitats through short swards will remain important for maintaining populations in cooler regions of the species' range, and in cooler years (O'Connor, Hails & Thomas 2014). The potential adverse impact of extreme summer heat and drought highlights the need to ensure fine scale heterogeneity in sward and shade to promote micro-refugial areas. Habitat restoration and creation should be used to strengthen downland ecological networks to promote the colonisation of new sites.

- Ensure sites that support the Adonis blue are managed to ensure small-scale structural heterogeneity within the habitat, with shorts swards and patches of long grass and scrub. Short swards are needed for both generations of the butterfly, but are most important in late summer for the second generation. Patches of taller vegetation and isolated scrub are needed to provide shading and potential micro-refugial areas on sites susceptible to drought. Cattle grazing will produce this variation in structure, which is also important for other chalk grassland butterfly species.
- To ensure suitable sward conditions stocking levels may need adjustment to compensate for changes in rabbit populations.
- Identify and manage appropriately sites that have populations of horseshoe vetch within the Adonis blue's current and former range, to promote natural spread and colonisation.
- Restore or create habitat in close proximity (< 500m) to existing sites to strengthen the ecological network.
- Translocation to sites outside the natural colonisation range of the species, including those to the north of its current range, should be considered where the management of these sites can provide suitable microclimate.

13 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Relevant Countryside Stewardship options

GS6 Maintenance of Species Rich Grassland

GS7 Restoration towards Species Rich Grassland

GS8 Creation of Species Rich Grassland

WD7 Management of successional areas and scrub

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Alpine lady's-mantle *Alchemilla alpina*
© Natural England/Derek Ratcliffe

Alpine lady's-mantle *Alchemilla alpina* L.

Climate Change Sensitivity:	HIGH	Ability to Manage:	LOW
Non climatic threats:	LOW	Vulnerability:	HIGH

Summary

Alpine lady's-mantle *Alchemilla alpina* is a montane species which in England is confined to the Lake District and North Pennines. It is likely to decline and potentially disappear from England with rising temperatures, although it might persist in refugial locations, and the chances of this could be increased by local translocation. It is relatively common in parts of the Scottish Highlands and elsewhere in Europe.

Description

Alpine lady's-mantle is a member of the Rosaceae, with distinctive palmate compound leaves and green flowers. It is a perennial plant with a woody rhizome. Maximum height is approximately 20 cm, although it is typically less than 10cm. It is apomictic, meaning seeds are produced without fertilisation.

Modelling indicates that the species is likely to lose all suitable climate space within England with 2°C warming, but will persist in the coldest parts of the Scottish Highlands (Pearce-Higgins *et al* 2015). Locally cooler places might allow the species to persist longer. However, work by Trivedi *et al* (2008a, b) shows that *A. alpina* and other artic-alpine species may be more vulnerable than large scale models suggest as they already occupy the coldest places within 10km grid squares.

Ecology and Distribution

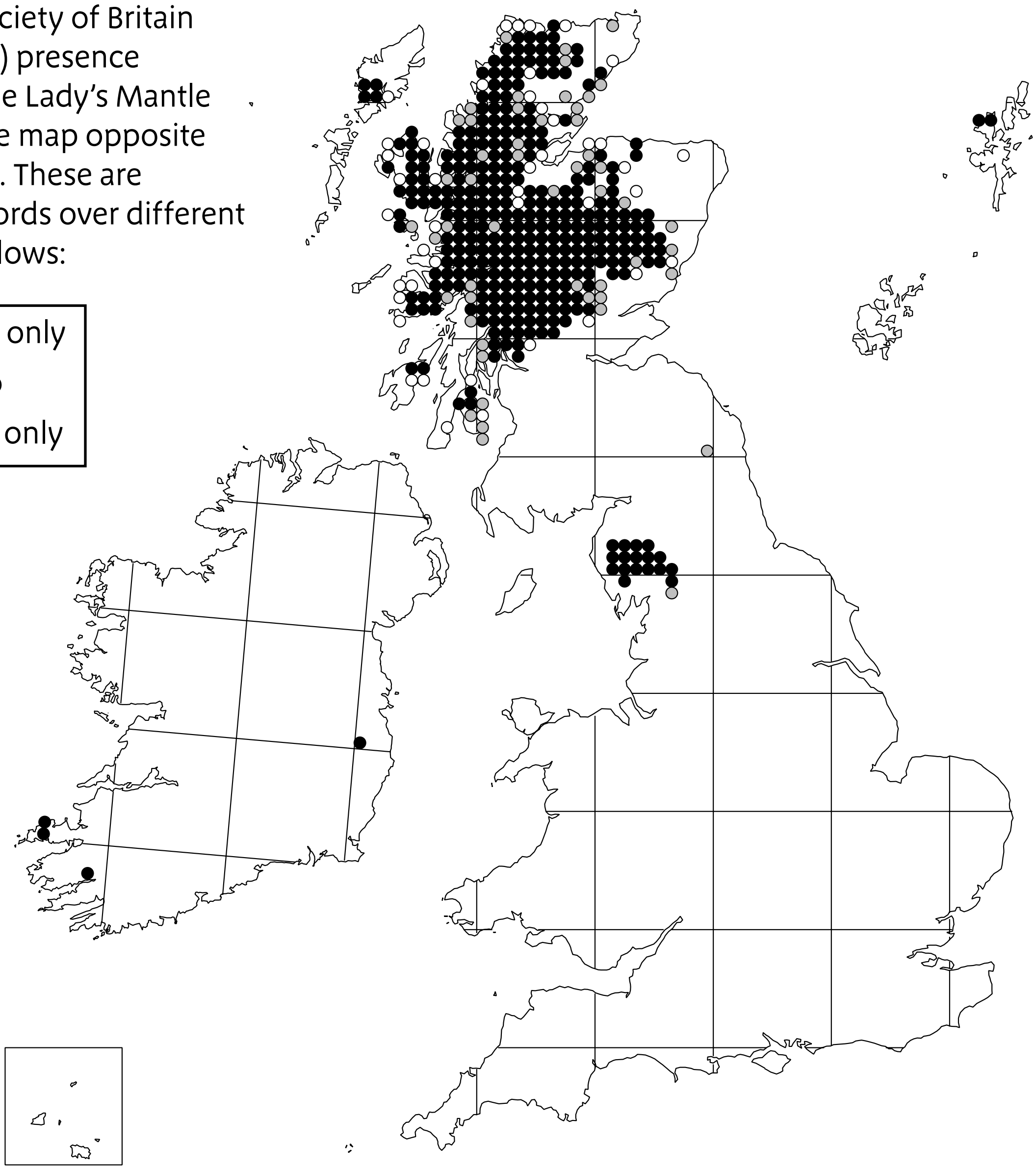
The natural distribution of Alpine lady's-mantle in England is confined to upland areas of the Lake District and North Pennines. It is relatively common in the Scottish Highlands and is found across northern and mountainous areas of Europe.

The New Atlas of the British and Irish Flora (Preston, Pearman & Dines 2002) describes its habitat as 'montane grassland and grass-heath, scree, cliffs, rocky stream sides, rock crevices and ledges. It is found in well-drained habitats, in areas of solifluction and late snow-lie, and sometimes on mountain slopes subject to severe wind-scour. The soils range from acidic to strongly calcareous. It is frequently washed down to lower levels on river gravels. It is found at a range of altitudes from near sea level in north-west Scotland to the tops of Scottish mountains, although at lower altitudes it is typically restricted to places with thin rocky soils and sparse vegetation. More broadly it is found in the colder parts of Europe and its distribution can be described as European Arctic–montane (Preston & Hill 1997).

Presence of Alpine lady's mantle records at 10km² scale provided by the BSBI and are based on records collected mainly by BSBI recorders.

The Botanical Society of Britain and Ireland (BSBI) presence records for Alpine Lady's Mantle are shown on the map opposite (10km grid scale). These are displayed as records over different time slices as follows:

- (grey circle) = 1987-2020 only
- (black circle) = 1930-2020
- (white circle) = 1930-1986 only



Alpine lady's mantle (*Alchemilla alpina*) and wild thyme (*Thymus praecox* subsp. *arcticus*) close-up detail. Wester Ross. Scotland. July. © Mark Hamblin (rspb-images.com)

Confidence in climate change impacts[14]

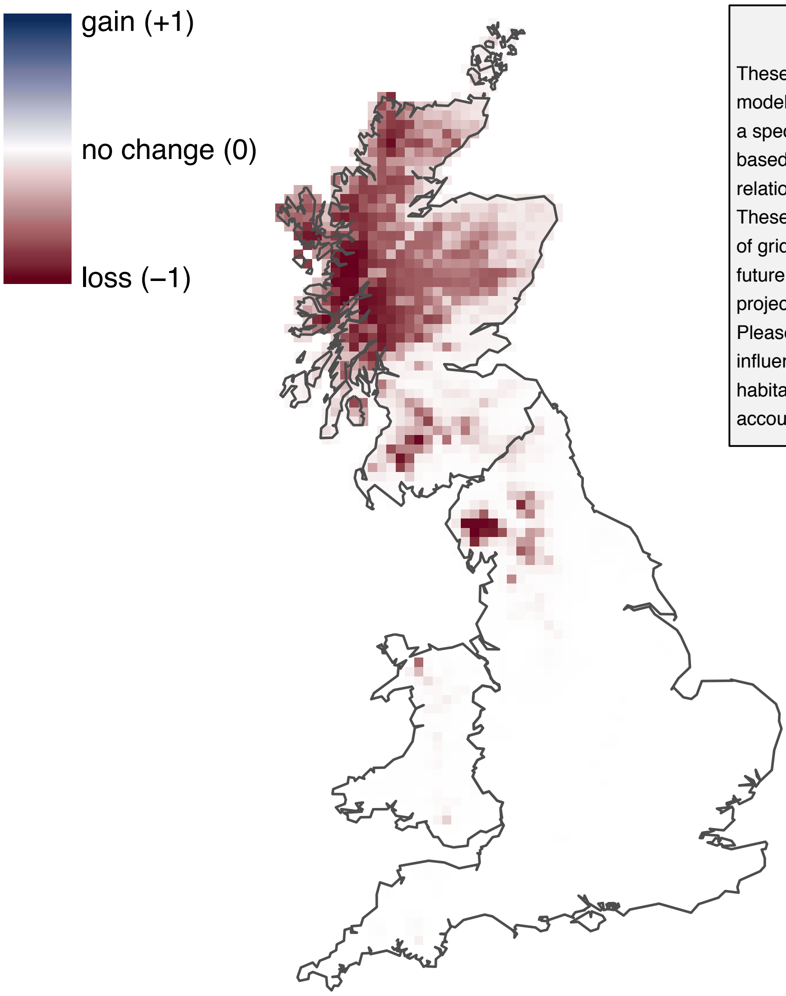
Distribution change: **HIGH CONFIDENCE** Mechanism: **MEDIUM CONFIDENCE**

Alpine lady's-mantle is found in relatively cold locations in the UK and its distribution would be expected to decrease with rising temperatures. It is probably restricted to cold places because it is not able to compete with species that are adapted to warmer conditions, and in the absence of competition it can grow in gardens at significantly higher temperatures. There is likely to be an interaction with soil; as plant growth increases soil may become deeper or start to accumulate on rocky areas, which may in turn support growth of a denser and taller sward. Similarly, atmospheric nitrogen deposition may promote growth of competitor species. Morecroft *et al* (1996) also noted that mortality of *A. alpina* increased with nitrogen input in a transplant experiment.

Modelling indicates that the species is likely to lose all suitable climate space within England with 2°C warming, but will persist in the coldest parts of the Scottish Highlands (Pearce-Higgins *et al* 2015). Locally cooler places might allow the species to persist longer. However, work by Trivedi *et al* (2008a, b) shows that *A. alpina* and other artic-alpine species may be more vulnerable than large scale models suggest as they already occupy the coldest places within 10km grid squares.

14 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Projected change in potential distribution of Alpine lady's mantle in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015)

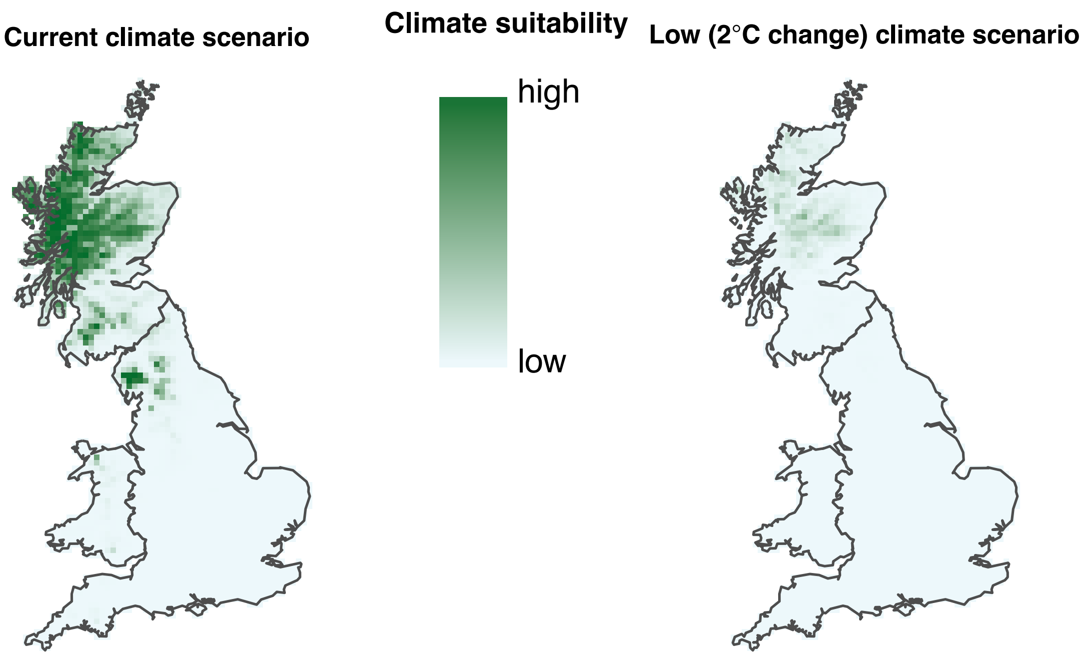


Climate suitability

These maps are created using statistical models which describe the probability that a species will be found in a 10 km grid square, based on its current distribution and its relationship to a number of climatic variables. These can be used to model the suitability of grid squares for a species under possible future climates when climate change projections are taken into account. Please note that other variables that influence species distributions, such as habitat and land–use change, are not accounted for in the modelling process.

Confidence of change

This species was not included as part of Natural England's Research Report NECR175 assessing the risks & opportunities for species in England as a result of climate change, so no assessment of confidence has been made for this species



Created by:	University of York	Created for:	Natural England	Created on:	August 18 2016

Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

There are few management options to maintain Alpine lady's-mantle in England in the long-term in a warming climate. However, it is a long lived, stress-tolerant species and is likely to be able to persist for years or even decades in sub-optimal conditions. If global climate change is successfully limited to well under 2°C it may survive in well drained sites with thin soils in the coolest parts of the landscape, such as high-altitude north-facing slopes.

Three possible interventions are:

- Remove competitor species manually. Given the abundance of the species in Scotland it would probably not be a priority use of resources in England, although it might be carried out on a small scale.
- Transplant into potential refugia where it does not currently occur (high altitude, north facing sites on thin soil). The species can be successfully transplanted in turves (Rawes and Welch 1972).
- Adjusting grazing levels. The optimal level of grazing is unclear – Rawes and Welch (1972) found that *A. alpina* is relatively tolerant of grazing, and grazing may be beneficial in limiting the impact of competitor species.

Reducing nitrogen deposition is also likely to benefit this species.

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Atlantic salmon
© Mark Hamblin (rspb-images.com)

Atlantic salmon *Salmo salar* (Linnaeus)

Climate Change Sensitivity:	HIGH	Ability to Manage:	MEDIUM
Non climatic threats:	HIGH	Vulnerability:	HIGH

Summary

The Atlantic salmon *Salmo salar* is native to the UK. It has an anadromous[15] lifecycle, and requires good water quality and river morphology, together with an unimpeded migration route to and from the sea. Although the Atlantic salmon occupies a large range, populations have been greatly impacted by poor water quality, engineered barriers to migration and exploitation. Climate change now represents an increasing threat to Atlantic salmon populations, potentially resulting in a northerly shift of the population and the loss of salmon from rivers in the south of England. Habitat restoration is required to both reduce increases in water temperature and re-open areas of catchment previously lost to engineered barriers to mitigate for any losses of habitat in the southern areas of the salmon range.

15 Anadromous fish migrate from the sea to fresh water to spawn

Description

The Atlantic salmon *Salmo salar* is the only native salmon to the UK. It is an anadromous species, with the freshwater phase requiring cool, swift-flowing streams and rivers (although it can also occur in lakes), with good water quality, clean gravels, physical habitat complexity that provides shallow water and flow refuges for juveniles, deeper water for adults, and an unimpeded river corridor for adult and smolt migrations.

Spawning takes place in shallow, gravelly areas where the water flows swiftly. The juvenile 'parr' spread out into other parts of the river. After a period of 1-6 years, the young salmon migrate downstream to the sea as 'smolts'. If they survive at sea, most salmon return to spawn in the river of their birth after 1-3 years. A small percentage of individuals do not return to their natal river and instead choose a different river in which to spawn.

Adults returning to freshwater vary greatly in size. Atlantic salmon are normally found in the range of 40 – 70cm in length and 1 – 5kg in weight, however, they can achieve much larger sizes with the current UK rod caught record standing at 29kg.

Ecology and Distribution

Historically, the species was widely distributed in all countries whose rivers enter the North Atlantic. In the UK, Atlantic salmon are widely distributed in suitable river systems not affected by poor water quality or barriers to upstream migration throughout Scotland, Wales, northern and southwestern England, together with a number of southern English chalk streams. The main distribution gap in England is from rivers entering the sea between the Yorkshire Esk and the River Itchen in Hampshire. Recent improvements in water quality have allowed the species to return to some rivers from which they have been absent for most of the last century, including several previously grossly polluted waterways, such as the River Mersey and River Trent catchments.

Salmon rivers vary considerably in their ecological and hydrological characteristics and in the life-cycle strategies adopted by the salmon within them. There are particularly strong contrasts between southern and northern rivers. The UK's varied climate, geology and terrain means that high diversity can be found within many large rivers. The cool and wet climate in the north, often with harder, more resistant rocks and steeper gradients, result in rivers that are sparsely vegetated, nutrient-poor and prone to spate flows in response to heavy rain or snow-melt. As a result, salmon may take up to three years to reach the smolt stage and migrate to sea. In the south, rivers flow across lower gradient terrain and softer rocks, in a warmer, drier climate. Here, salmon often grow sufficiently quickly to smolt as yearlings.

The Atlantic salmon is a keystone species in freshwater ecosystems, allowing the transport of nutrients from the marine environment to often nutrient poor upland rivers. This transfer of allochthonous[16] nutrients may help sustain the complex food webs and other species present in these headwater areas.

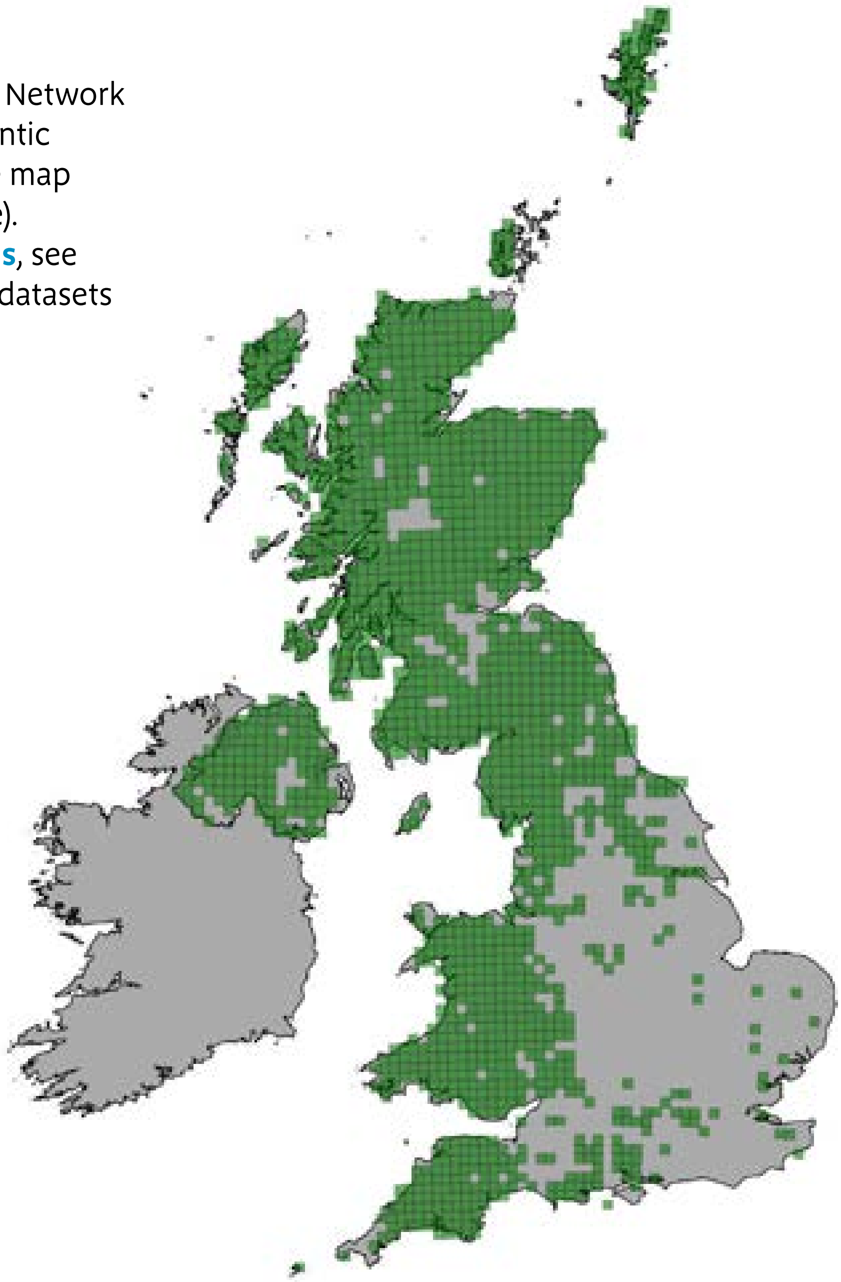
16 not formed in the region where found

Together with brown or sea trout, the Atlantic salmon forms a vital role in the life history of the freshwater pearl mussel *Margaritifera margaritifera*. The larvae, glochidia, are inhaled by juvenile Atlantic salmon and brown or sea trout. Glochidia then attach to the gills of the juvenile fish, encyst, live and grow in the hyper-oxygenated environment until the following spring when they drop off. Once widespread and abundant in areas of England and Wales, most former populations are virtually extinct or with very little active recruitment. Without healthy, sustainable populations of Atlantic salmon and trout to act as hosts for the glochidia, the remaining pearl mussel populations will continue to decline.

The UK's central location within the Atlantic salmon range, the diverse range of habitat offered by the rivers around the extensive island coastline and its proximity to known marine feeding grounds highlights the ecological importance of English rivers for the survival of the Atlantic salmon and other associated freshwater species.

Presence of Atlar

The National Biodiversity Network presence records for Atlantic salmon are shown on the map opposite (10km grid scale). (See **terms and conditions**, see Appendix 1 for the list of datasets included)



Climate Change Impacts

The recent distribution of Atlantic salmon has been restricted by anthropogenic effects, particularly engineered barriers to migration, deterioration in water quality, and the combined impacts of climate change. Consequently, the Atlantic salmon has declined or become locally extinct in many of the larger rivers.

Climate projections suggest that precipitation will tend to increase in the winter and decrease in summer. Wetter winters may result in more frequent and more extreme spring floods, and milder winters could lead to higher winter water temperatures. Hatching of eggs will be accelerated in the southern portion of the salmon's range, and juveniles will need to start feeding earlier in spring. It is likely that food organisms will be available, as they will also develop more rapidly at higher water temperatures. However, altered flood regimes may present a harsher environment for juvenile salmon.

Growth conditions in northern rivers are likely to improve, and so will the production of salmon smolts. In contrast, rivers in the southern part of the distribution range are likely to present salmon juveniles with warmer water at a lower run-off, which may reduce productivity. Altered flow regimes are likely to influence the timing of smolt migration and adult return. Warming of the freshwater and coastal marine environment is highly synchronous, and amplification of climatic process such as the North Atlantic Oscillation may combine to affect both the survival and growth of Atlantic salmon, leading to a northern shift in range.

Increased water temperatures associated with climate change may be particularly pronounced on the southern edge of the English Atlantic salmon range. If the expected northward movement of the thermal niche of anadromous salmonids occurs, decreased production and population extinction in the southern part of the range may result in a loss of salmon from southern chalk streams draining to the south coast.

Please read this case study alongside the relevant habitat sheets.

Adaptation Options

Improvements in water quality due to reductions in both diffuse and point source pollution, combined with the removal of engineered barriers to migration will continue to open up new areas of river catchments in England. Functional freshwater habitat is vital to maximise juvenile production. When considering options for improving fish passage, the best solution generally is total removal of the obstruction, as the geomorphological benefits gained by removal may enhance spawning gravel quality, increase habitat heterogeneity and increase food production for fry and parr.

Tree planting alongside headwater streams and rivers may provide a sufficient cooling effect (Woodland Trust, 2016) to stop water temperatures causing direct physiological stress for adults and/or juveniles, or secondary effects such as food shortages or initiating migratory avoidance responses. In certain areas, water blending from impoundments may also be regulated in such a manner as to provide both sufficient flow and suitable water temperatures for salmon migration. Exploitation controls such as net limitation orders, fishery buyouts and catch and release schemes may further reduce fish mortality.

These factors will assist in the maintenance of Atlantic salmon populations in England, however, they may not fully compensate for marine mortality and the effects of climate change on both the marine and freshwater environment. It appears likely that, although the available functional freshwater habitat suitable for salmon may increase in England, the overall population numbers may continue to fall in many areas, particularly in southern England. Although it may ultimately not be technically feasible to prevent a decline in salmon stock from southern areas, all feasible climate change adaptation methods should be implemented on southern salmon rivers to delay the loss of the species from these areas, while restoration of northern rivers should continue to open up historic habitat from which salmon have been excluded by human activity.

One potential mitigation option which should be discouraged is the removal of natural barriers, which would allow access to new areas of a catchment from which migratory species have been excluded for a long time. Under these circumstances, the integrity of the existing upstream species community should be maintained.

Relevant Countryside Stewardship options

To address the in-river and wider catchment issues impacting negatively on Atlantic salmon populations in England, Countryside Stewardship may be used to fund measures to restore the naturally functioning freshwater habitat required for sustainable salmon populations. Countryside Stewardship includes a number of options intended to reduce run-off and siltation of spawning habitat, improve water quality, and reduce water temperatures within rivers. Relevant options to consider include:

SW1 4 - 6 m buffer strip on cultivated land

SW2 4 - 6 m buffer strip on intensive grassland

SW4 12 - 24m watercourse buffer strip on cultivated land

SW5 Enhanced management of maize crops

SW6 Winter cover crops

SW7 Arable reversion to grassland with low fertiliser input

SW8 Management of intensive grassland adjacent to a watercourse

SW9 Seasonal livestock removal on intensive grassland

SW10 Seasonal livestock removal on grassland in SDAs next to streams, rivers and lakes

SW11 Riparian management strip

SW12 Making space for water

UP3 Management of moorland

UP5 Moorland re-wetting supplement

Case Study

In 2012, Eden Rivers Trust, and project partners the Environment Agency and Natural England, began planning a river restoration project on the River Lyvennet, a tributary of the River Eden, at Barnskew in Cumbria. A 2km section of the River Lyvennet and the Howe Beck, an associated tributary, had been historically straightened and dredged for land management purposes. Bed material was predominantly boulder and cobble, with riparian land use a mixture of rough pasture, silage and commercial non-native forestry.

Prior to restoration, the River Lyvennet was known to contain Atlantic salmon, brown trout, bullhead, and native crayfish. However, habitat was often suboptimal for these species. The straightened section offered a poor range of habitats and flow types, with limited floodplain connectivity due to engineered boulder bank revetment. Riparian habitat was also poor with heavily grazed rough pasture and conifer plantation.

The project focused on re-meandering the river by reconnecting it to a pre-selected and excavated paleo channel. Channel selection was undertaken using LIDAR imaging. The restoration process benefited from using the remnant channel as stream bed material was readily available, which increased the speed of recovery and reduced project costs. The process increased stream length by more than 20% and re-established the natural meander pattern, slope and cross section.

The project has resulted in the restoration of natural stream processes and increased habitat heterogeneity, in both the channel and riparian areas. Although erosion has been exacerbated in some areas due to a lack of bankside vegetation and the active nature of the channel, it is expected to stabilise rapidly as deeper-rooted tree and other plant species become established. Following completion of the re-meandering, Atlantic salmon have been seen spawning in the restored river section. This demonstrates the importance of high quality gravels and spawning habitat being made available, and the willingness of salmon to exploit these new resources.

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Sphagnum balticum (right) growing with *Sphagnum papillosum*.
© David Reed, Cyfoeth Naturiol Cymru/Natural Resources Wales

Baltic Bog-moss *Sphagnum balticum* (Russow) C.E.O. Jensen

Climate Change Sensitivity:	HIGH	Ability to Manage:	MEDIUM
Non climatic threats:	MEDIUM	Vulnerability:	HIGH

Summary

Baltic bog-moss is a nationally rare and endangered bryophyte that is now restricted to four known sites in Britain, having been lost from several sites in the last century due to development, drainage and afforestation. It is considered likely that it is vulnerable to the effects of climate change as it requires very cold winters for optimum growth, and is most prolific in the Arctic tundra and northern boreal zone. Thus, more frequent mild winters in Britain are likely to be damaging to the species, giving other more common species of bog-moss a competitive advantage.

Baltic bog-moss is also vulnerable to changes in hydrology and water quality, and may be adversely affected by atmospheric nitrogen pollution. The management of existing sites to ensure optimum conditions is of prime importance for the protection of the species in Britain. In addition, the restoration of former sites, or the creation of new sites, in parts of the country that will remain climatically suitable for the species should be considered, possibly combined with species introductions or reintroductions where restored sites are distant from existing populations.

Description

Baltic Bog-moss is a small species of bog-moss, usually pale brown, yellowish-brown or orange-brown in colour, although green forms may occur in extremely wet or shaded conditions (Hodgetts, 2012). It may occur as scattered plants, or form patches or carpets. The bog-mosses can be recognised by their distinctive growth form, in particular the capitulum (head) of short, densely-arranged branches above a weak stem that carries clusters of branches with leaves that closely overlap, often in neat ranks. Baltic bog-moss has spreading stem leaves and branches in bundles of three on a pale stem. It is well known for being difficult to identify in the field due to its similarity with other species of bog-moss, and for being sensitive to trampling, thus surveys for the species should be carried out by expert bryologists. Baltic bog-moss is nationally rare (Pescott, 2016), endangered (Hodgetts, 2011), and is protected under Schedule 8 of the Wildlife & Countryside Act 1981.

Ecology and Distribution

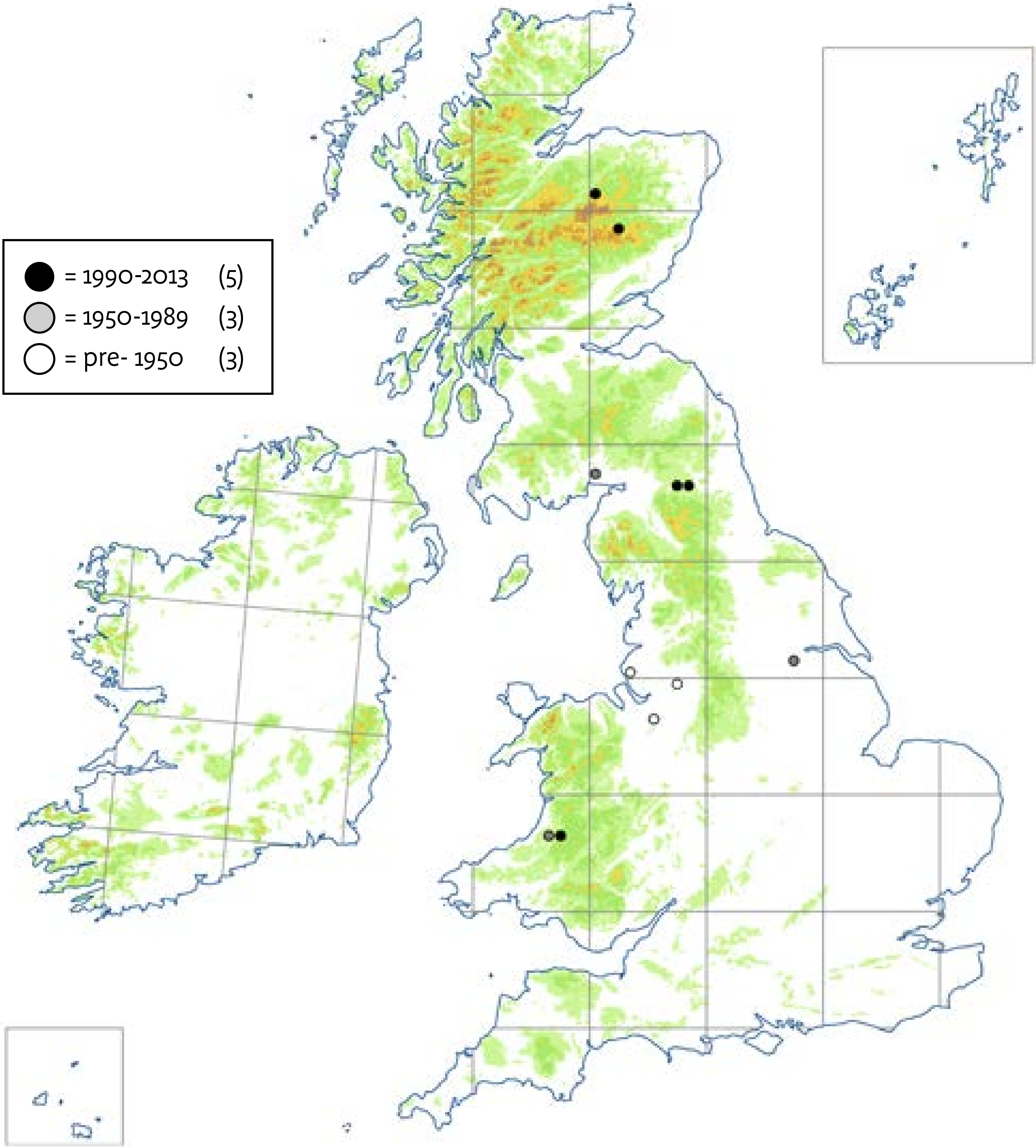
Baltic bog-moss grows primarily in nutrient-poor raised bogs that are fed by rain water (ombrotrophic), and also in marginal areas of valley bogs. More rarely it occurs in blanket bogs. It favours very wet conditions, with a water table that occurs about 5 cm below the surface, and in such conditions may form carpets. It typically occurs close to bog pools and channels, in wet peat cuttings, and in the hollows of hummock-hollow bog habitats. In less waterlogged areas it may occur as small and scattered individual plants. It is mainly a lowland species in Britain, but reaches an altitude of 660m in Scotland (Hodgetts, 2012). Other species that frequently grow with it include red bog-moss *Sphagnum capillifolium*, papillose bog-moss *S. papillosum*, Magellanic bog-moss *S. magellanicum*, flat-topped bog-moss *S. fallax*, common cottongrass *Eriophorum angustifolium*, bog rosemary *Andromeda polifolia*, cranberry *Vaccinium oxycoccos* and cross-leaved heath *Erica tetralix*.

Within Britain, Baltic bog-moss currently occurs at two known sites in Scotland, one in Wales, and one in England (the site in northern England extends over two hectads, hence the two adjacent dots on the map). The species also occurs in northern Asia, North America, Greenland, and the Baltic countries. It is typically continental in distribution and extends as far south as the Alps.

In addition to being vulnerable to the effects of climate change, Baltic bog-moss has also been badly affected in Britain by habitat loss (Blockeel *et al* 2014). Out of five sites in England, four were lost before 2000 (Porley, 2013). Causes of these losses have been site destruction for development and the loss of bog vegetation to forestry. A site in Scotland has been affected by draining and afforestation.

Presence records for Baltic bog-moss from the Atlas of British & Irish Bryophytes produced by the British Bryological Society are shown on the map below (10km grid scale).

Presence of Baltic bog-moss records, 10km², © British Bryological Society 2014 (Blockeel *et al* 2014).



Confidence in climate change impacts[17]

Distribution change: **HIGH CONFIDENCE** Mechanism: **LOW CONFIDENCE**

Baltic Bog-moss is on the edge of its range in Britain. It is a member of the circumpolar Boreo-Arctic montane element that requires very cold winters for optimum growth, and it is most prolific in the Arctic tundra and northern boreal zone. It only fruits in quantity in the Arctic regions, and is not known to fruit in Britain (Daniels & Eddy, 1990). This requirement for very cold winters makes Baltic bog-moss poorly suited to likely climate change effects in Britain, including more frequent mild winters, which may give other species of bog-moss a competitive advantage. This may make more southerly sites increasingly less suitable for the species.

In addition, Baltic bog-moss is vulnerable to changes in hydrology, in particular any lowering of the water table that is likely to result in desiccation of the bog habitat and colonisation by other species (Hodgetts, 2012). It is also vulnerable to changes in water quality, and to increased levels of atmospheric carbon dioxide and nitrogen, which may give other bryophytes and vascular plants a competitive advantage. Van der Heijden *et al* (2000) recorded that both elevated levels of atmospheric CO_2 and increased nitrogen resulted in increased growth of the papillose bog-moss *Sphagnum papillosum*, but that in contrast Baltic bog-moss did not show increased growth in these conditions.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

The most effective adaptation options for Baltic bog-moss are likely to be management of existing sites to ensure optimum conditions for the species, and the restoration of areas within its existing range, possibly combined with species introductions or reintroductions where restored sites are distant from existing populations. Restoration should focus on areas likely to remain more climatically suitable for the species, namely northern areas in Britain.

- Ensure optimum management of existing sites through the appropriate management of water levels, in particular maintaining the very wet conditions favoured by the species. Such wet conditions will help limit colonisation by trees, scrub and taller vegetation that are likely to invade if sites dry out. Water quality should be managed to preserve oligotrophic, acidic conditions.
- Ensure bogs supporting Baltic bog-moss are not excessively trampled, either by livestock or surveyors. Surveys for the species should be carried out by expert bryologists who are familiar with the species, to minimise impacts on the habitat.
- Consideration should be given to restoring suitable habitat in areas of the country likely to remain climatically suitable for the species.
- Consideration should be given to reintroducing or introducing the species to areas of the country likely to remain climatically suitable for the species.
- Monitoring will help to determine population trends and the effectiveness of interventions, however this should be very carefully designed to ensure that it does not cause damage to the species, in particular by trampling by recorders.

17 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Relevant Countryside Stewardship options

WT10 Management of lowland raised bog

FM2 Major preparatory works for Priority Habitats (creation and restoration) and Priority Species

SP9 Threatened species supplement

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Beech in mature woodland
© Natural England

Beech *Fagus sylvatica* L.

Note: This species account should be read alongside that for Beech and Yew Woodland habitat

Climate Change Sensitivity:	MEDIUM (HIGH FOR DROUGHT)	Ability to Manage:	MEDIUM
Non climatic threats:	LOW	Vulnerability:	MEDIUM

Summary

Beech is vulnerable to the increased threat of drought with climate change in the south and east of its range, but it has the potential to grow well in north western areas. Adaptation will depend on the management objectives for a site and the area of the country. Where conservation is the priority, it is likely to be possible to maintain beech under moderate levels of climate change even in drought prone areas, but there will be a risk of mortality following hot dry summers. Diversification with other native species less vulnerable to drought is likely to be desirable to reduce risks of large scale loss of canopy cover in southern and eastern areas. Where timber harvesting forms part of site objectives, ensuring a diversity of species with a higher degree of drought tolerance will be even more important. In northern and western areas, beech is likely to remain viable for both biodiversity and production; the practice of removing beech as a non-native species is not recommended in these areas.

Description

Beech is a large, shallow rooted, deciduous tree, native to southern England. Mature beech can grow to a height of more than 40m. Within closed canopy woodlands, beech forms a dense canopy and casts a deep shade. Solitary beech trees have a wide, dense crown and low branches which hang down and also create shady conditions. Beech seeds survive better than those of many other tree species in strong shaded conditions and seedlings are able to survive and grow below the canopy of established trees (Rodwell 1991).

Beech trees normally come into leaf in April or May and after senescence retain dry, coppery foliage late into winter.

Beech is monoecious with separate male and female flowers on the same tree, in April and May. The tassel-like male catkins hang from long stalks at the end of twigs, while female flowers grow in pairs, surrounded by a cup. Beech is wind pollinated.

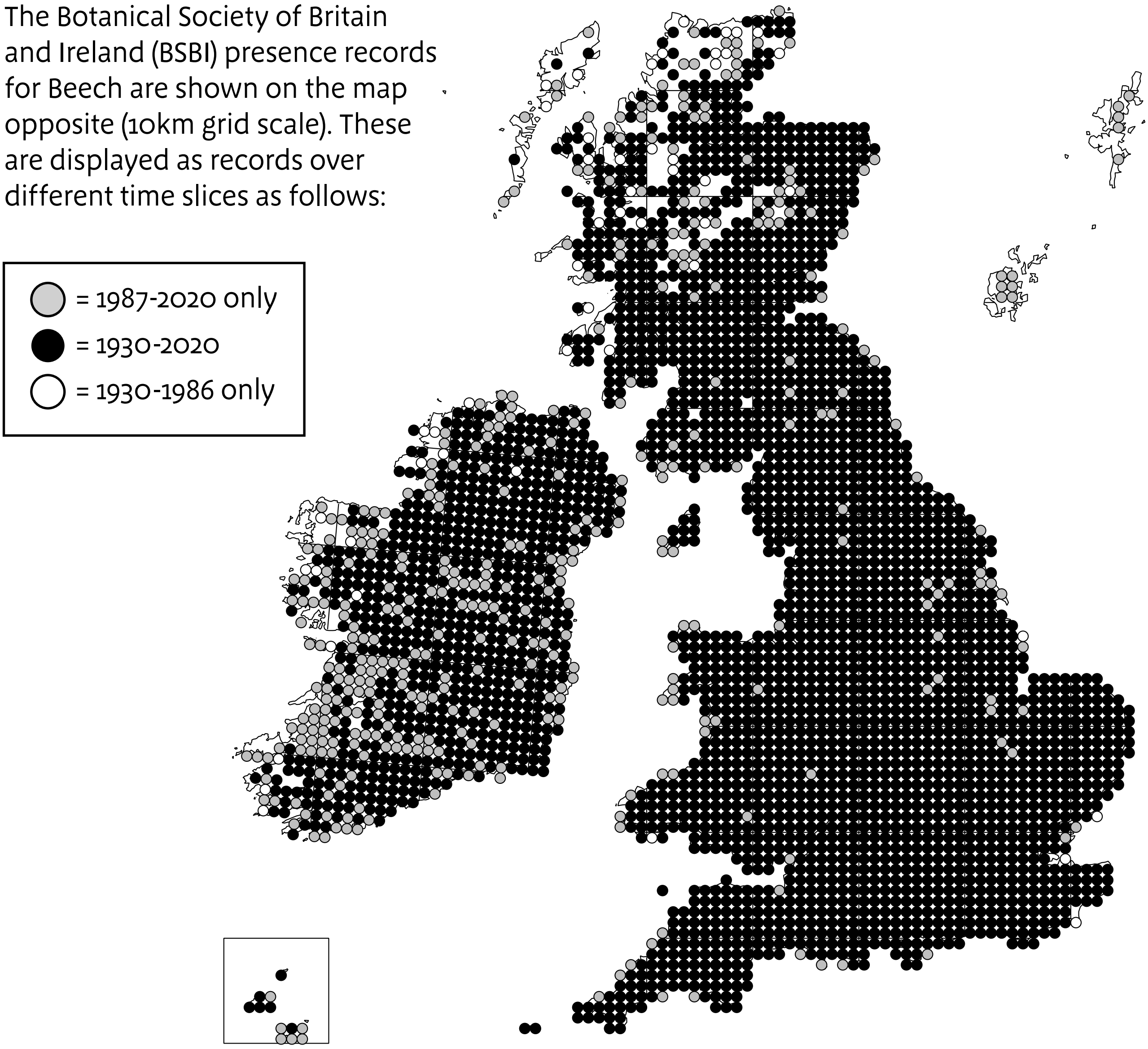
Ecology and distribution

Beech grows best on base rich soils, but tolerates any well-drained soil. It does not grow well on heavy clay soils. It often grows in single species stands, although this partly reflects past management, for example to produce wood for the furniture industry in the Chilterns. It is also widely found as pollards in wood pasture. Beech was present in southern Britain when the country became an island after the last Ice Age, and subsequently spread northwards to an approximate line between the Wash and the Bristol Channel, limited by summer drought in parts of East Anglia (Packham *et al* 2012). Beech also grows well further north: it has been widely planted and can naturally regenerate; it may well have spread naturally to the north of Britain without human intervention.

Beech is a common species across much of Europe and is a commonly grown timber tree in central Europe. The importance of the UK for beech will increase under climate change, with the species expected to be lost or decline from parts of its range in southern and central Europe.

Presence of Beech records at 10km² scale provided by the BSBI and are based on records collected mainly by BSBI recorders.

The Botanical Society of Britain and Ireland (BSBI) presence records for Beech are shown on the map opposite (10km grid scale). These are displayed as records over different time slices as follows:



Confidence in climate change impacts[18]

Distribution change: **HIGH CONFIDENCE** Mechanism: **HIGH CONFIDENCE**

Beech is vulnerable to a range of potential impacts, particularly drought (Cavin and Jump, 2017; van der Maaten-Theunissen *et al* 2016). Effects of other changes on growth characteristics and competitive ability may also become apparent over a period of decades.

Due to its shallow rooting, beech is sensitive to drought leading to reduced water and nutrient availability (Peterken & Mountford 1996). This leads to the suppression of growth and sometimes the death of mature trees (Cavin *et al* 2013) and seedlings. The incidence of beech decline linked to the *Phytophthora* fungus may also increase as summer drought stress becomes more frequent and severe (Broadmeadow & Ray 2005).

18 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

At higher altitude and at the northern margin of its range where temperature controls growth, warming has been shown to increase the growth rate of beech (Dulamsuren *et al* 2017), to advance spring bud burst, and extend the growing season in the autumn (Schieber, Kubov & Janík 2017).

In the south and east, climate change is likely to lead to a reduction in its competitive ability within mixed woodland compared to species such as sessile oak *Quercus petraea* (Cavin *et al* 2013, Mette *et al* 2013). At its southern range margin in Europe, climate change is resulting in a progressive replacement by Holm oak *Quercus ilex* in the higher parts of the Pyrenees (Penũelas & Boada, 2003). The main causes are reduced recruitment and increasing defoliation of beech. Other studies have shown that long-term drought stress has reduced the productivity of beech forests at the southern range edge (Jump *et al* 2006).

Whilst beech is clearly sensitive to drought in the Southern England (Cavin and Jump 2017), local factors, including soil and geology can reduce risk in some locations. There is evidence that beech growing in shallow soils on chalk can access water in the chalk itself as a result of its hydrological properties (Roberts and Rosier, 2005), making it less vulnerable than might otherwise be expected.

Beech is also sensitive to water-logging and flooding (Geßler *et al* 2007, Packham *et al* 2012), suggesting that across its entire range it will be susceptible to changes in the pattern of rainfall and the frequency of extreme rainfall events. Higher water tables reduce the penetration of roots, making the tree more susceptible to drought. Seasonal shifts in rainfall (increased winter rainfall and decreased summer rainfall) may therefore increase the sensitivity and exposure of beech to drought.

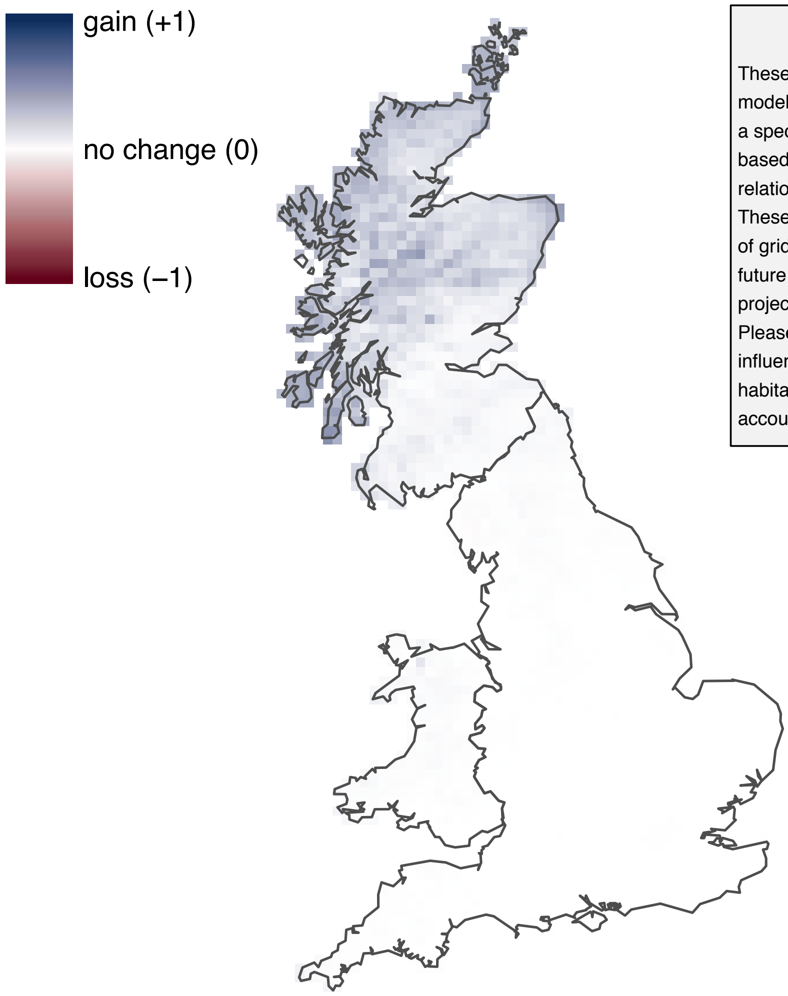
The flowering and subsequent seeding of beech is adversely impacted by late frosts (Packham *et al* 2012) and climate change driven warming may reduce this effect, leading to increased seeding.

Due to its ability to grow on shallow soils, beech is vulnerable to strong winds (Packham *et al* 2012) and therefore may be adversely impacted by any increase in storminess. The thin bark of beech makes it vulnerable to fire, the threat of which is likely to increase under climate change, at least in the south.

Beech regeneration is adversely impacted by high numbers of squirrels (Packham *et al* 2012), populations of which could increase due to reduced mortality during milder winters and increased summer food supply. As with many species of trees, climate change induced stress may increase the susceptibility to plant diseases such as *Phytophthora*.

In experimental trials, saplings from populations of beech in drier areas of their range were less sensitive to drought (Alarcon 2017). Genetic variation along temperature gradients have also been shown (Kramer *et al* 2010), suggesting that genetic variation within the population may provide some element of tolerance to climate change. However, the ability of beech to adapt is unlikely to keep pace with the rate or extent of climate change.

Projected change in potential distribution of beech in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015)

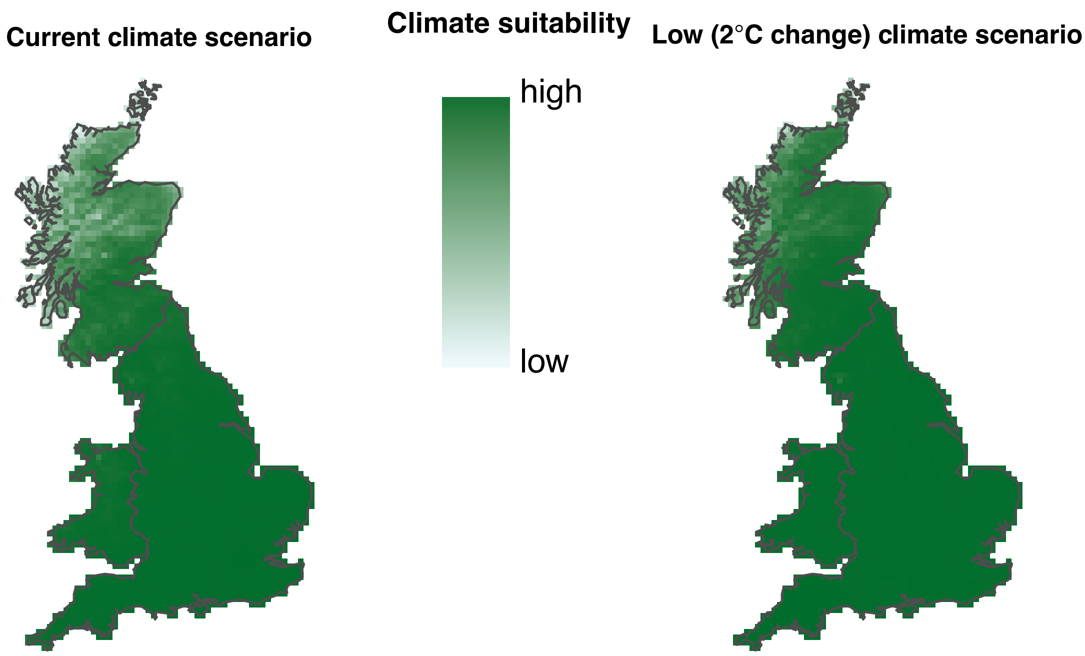


Climate suitability

These maps are created using statistical models which describe the probability that a species will be found in a 10 km grid square, based on its current distribution and its relationship to a number of climatic variables. These can be used to model the suitability of grid squares for a species under possible future climates when climate change projections are taken into account. Please note that other variables that influence species distributions, such as habitat and land–use change, are not accounted for in the modelling process.

Confidence of change

This species was not included as part of Natural England's Research Report NECR175 assessing the risks & opportunities for species in England as a result of climate change, so no assessment of confidence has been made for this species



Created by:	University of York	Created for:	Natural England	Created on:	August 18 2016

Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture reductions in growth or canopy cover, which may be large in parts of southern England – see above text for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

As with many tree species, the approach to adaptation for beech will depend on whether it is being managed for conservation, timber production or a combination of objectives. This section focuses on the species' ecological status and its role within the woodland community; further information on adaptation in relation to timber production is available elsewhere (Ray *et al* 2010).

There are two broad approaches to adaptation: building resilience and adjusting objectives in response to inevitable changes. Both of these are important with beech and different approaches are appropriate in more drought prone areas of the south and eastern, where beech is considered native, compared to wetter areas in the north and west.

In drought prone areas:

- Promote increased diversity of native tree species to prevent the loss or degradation of the woodland habitat due to the loss or decline of beech.
- Promote natural regeneration to take advantage of natural genetic variation in populations in existing woodland managed for conservation.
- Where maintaining the survival of existing beech trees is a priority, consider direct management to reduce other pressures e.g. competition.
- Use planting or natural regeneration to increase the size of woodland patches to increase the area of woodland with cool, damp microclimate away from the edge.
- Encourage closed canopy management including continuous cover forestry to promote shade and cool microclimates and reduce vulnerability to drought and desiccation.
- Implement management that promotes natural hydrological function and retains water within soils, including ditch blocking.
- Consider planting or promoting deep-rooting trees such as oak alongside beech in drought prone areas, to improve the water balance of the soil via hydraulic lift of water from deeper aquifers.
- Control other threats in as much as this is possible, including the risks of herbivory by deer and squirrels.
- When planting new woodlands consider including provenances from warmer, drier conditions. See Whittet *et al* 2019 for a discussion of the relative merits of this compared to local seed sourcing of seed, in different circumstances.
- Ensure fire contingency plans are in place.

In the north and west

- Accept beech as a native species in areas that are now within its climate envelope and reflect in conservation objectives for sites, so long as this doesn't compromise other objectives.
- Consider planting beech as part of species mixtures in new woodlands.

Relevant Countryside Stewardship options

WD1 Woodland creation - maintenance payments

WD2 Woodland improvement

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Heather and bilberry sward
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Bilberry *Vaccinium myrtillus*

Climate Change Sensitivity:	MEDIUM	Ability to Manage:	MEDIUM
Non climatic threats:	MEDIUM	Vulnerability:	MEDIUM

Summary

Bilberry is an important species supporting upland birds such as ring ouzel *Turdus torquatus* and black grouse *Tetrao tetrix*, and many invertebrates. It's seed production is influenced considerably by climate. However as it reproduces primarily through vegetative growth, this is unlikely to represent a threat. Climate change is likely to operate through reducing its competitive ability compared to other species such as heather, bracken and grasses. At higher altitudes bilberry may benefit from warming, but in the south and east climate change is likely to pose a threat. Adaptation options mainly consist of ensuring the optimum conditions for bilberry growth and reproduction by manipulating the level of shading and grazing. Addressing *Phytophthora* and competition from other species is also likely to be important in the south of its range.

Description

Bilberry is a deciduous, rhizomatous dwarf shrub. It has a green, three angled stem with two or three ranks of leaves and, if mature, older woody shoots. The leaves are finely toothed and prominently veined on the lower surface. The flowers are 4-6mm long, are borne singly in leaf axils, and have five small calyx segments and a fused pink urn shaped corolla. The fruits are a purple-black berry (Ritchie 1956).

Ecology and distribution

Bilberry is a perennial plant that regenerates primarily by clonal growth of existing plants and only occasionally by seed. It is a major component of upland heaths and some lowland heaths and a range of similar habitats on acid substrates in the UK, extending in altitudinal range from near sea level to high mountain tops. Bilberry has undergone a significant decline since the 1950's in the south and east of England, mainly reflecting the loss and fragmentation of lowland heathland.

Seedlings are sensitive to drought, which may limit germination in areas subject to low humidity levels. Young plants are slow growing and take several years to reach maturity, but when well-established bilberry can spread over large areas via underground shoots.

It is an acid-loving plant that is common and locally dominant in well-drained to poorly-drained heaths and moorland and in the ground flora in acid beech, birch, pine and oak woodland. It also occurs on raised areas in peat bogs in the north and west (Richie 1956) or where drainage systems have lowered the water table. It grows on a range of soil types including deep peat, mineral soils, skeletal soils on scree and rock-faces, and free-draining sands. Bilberry has a markedly northern and western distribution in the UK. It is relatively rare in the east midlands and East Anglia, and where it is present it occupies parts of the landscape with cooler and more humid microclimates (Coudun & Gégout 2007).

Bilberry is relatively shade tolerant, and cover can increase with shading in certain situations (Parlane *et al* 2006). It may form dense stands in woodland. In open areas it can be outcompeted by heather and grasses. Bilberry is somewhat sensitive to selective grazing by deer and sheep, as this tends to reduce the height and competitive ability of the plant, as well as removing flowering tips. It will be out-competed by heather where both occur under moderate and high grazing regimes (Welch 1998). There are indications that bilberry is highly sensitive to uncontrolled heath fires in southern England, suggesting that the rootstock is vulnerable to heat damage in dry soil.

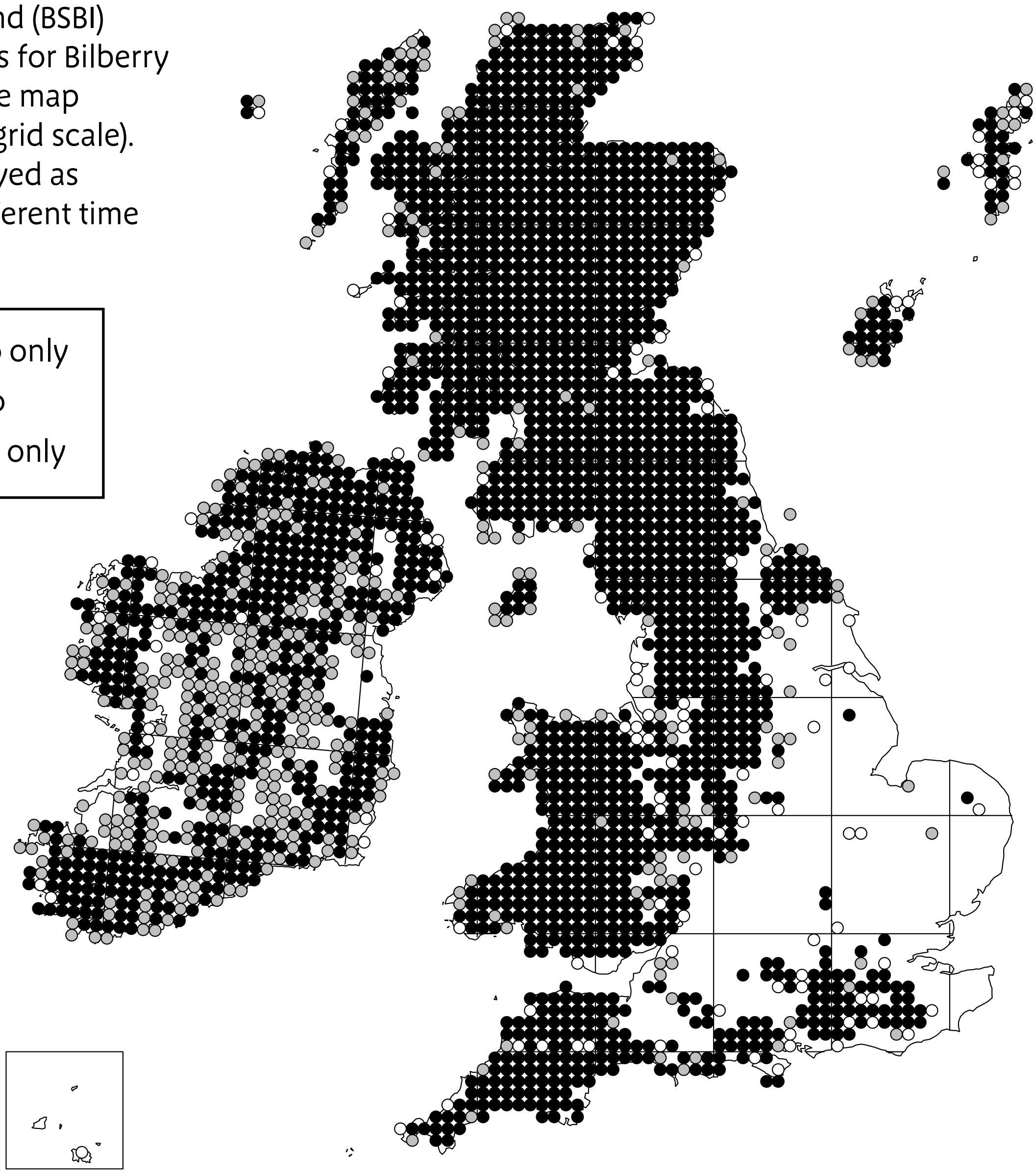
Bilberry is an important nectar-source. Its fruits are eaten by several species of birds and mammals and it is the sole food plant of scarce moths, including the bilberry pug *Pasiphila debiliata*, beautiful snout *Hypena crassalis* and northern spinach *Eulithis populata*. In lowland heathland situations, bilberry-dominated vegetation can provide nesting and foraging areas for birds, and important cover and thermo-regulation areas for reptiles such as sand lizard and smooth snake. Bilberry forms a hybrid with *Vaccinium vitis-idea*, the rare *Vaccinium x intermedium*, which is relatively common in the West Midlands. It is worth noting that if the parent bilberry is impacted by climate change it would also affect the hybrid. Bilberry can be present in 41 NVC communities which occur on approximately 1000 SSSIs across England. Some of these SSSIs are also Special Areas for Conservation (SACs). Bilberry is host to over 100 species of invertebrate.

Bilberry appears to have a high susceptibility to infection by the devastating fungus-like pathogens *Phytophthora ramorum* and *Phytophthora kernoviae*, which are implicated in sudden oak death and the death of beech trees. These are notifiable diseases which are considered a serious economic and ecological threat. In bilberry, the symptoms are stem lesions, leaf drop and rapid die-back of stems, which often affect extensive patches of the plant. The ecology of the pathogen is poorly understood but its spread is thought to be helped by humid conditions. Research indicates that bilberry may represent a potentially important host for the pathogens and therefore, where infected, bilberry may pose a threat to other susceptible plants.

Presence of Bilberry records at 10km² scale provided by the BSBI and are based on records collected mainly by BSBI recorders.

The Botanical Society of Britain and Ireland (BSBI) presence records for Bilberry are shown on the map opposite (10km grid scale). These are displayed as records over different time slices as follows:

- (grey circle) = 1987-2020 only
- (black circle) = 1930-2020
- (white circle) = 1930-1986 only



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Confidence in climate change impacts[19]

Distribution change: **MEDIUM CONFIDENCE** Mechanism: **MEDIUM CONFIDENCE**

Because bilberry seed requires a cold chilling period to break its dormancy (ACIA 2005), projected warming is likely to reduce climatic suitability in the south and east of the country. It appears to be sensitive to late season drought (Taulavuori *et al* 2010) making it vulnerable to the increased risk of more frequent and extreme summer droughts, especially in the south and east. In northern areas, warmer conditions in the winter and spring are associated with early de-hardening (frost tolerance), exposure to drought (Tahkokorpi, *et al* 2007, Rixen *et al* 2010; Selas *et al* 2015), and frost damage (Tolvanen 1997) linked to a reduction in snow cover (Tolvanen 1997; Blume-Werry *et al* 2016).

Seed production is also adversely affected by high temperatures and low or high amounts of precipitation during berry ripening in summer (Selas 2000). As the plant only rarely reproduces by seed, this is unlikely to have an impact on existing bilberry populations but will have an impact on the ability of the plant to colonise new or restored sites and will affect a wide range of species that feed on the berries (Moe *et al* 2018).

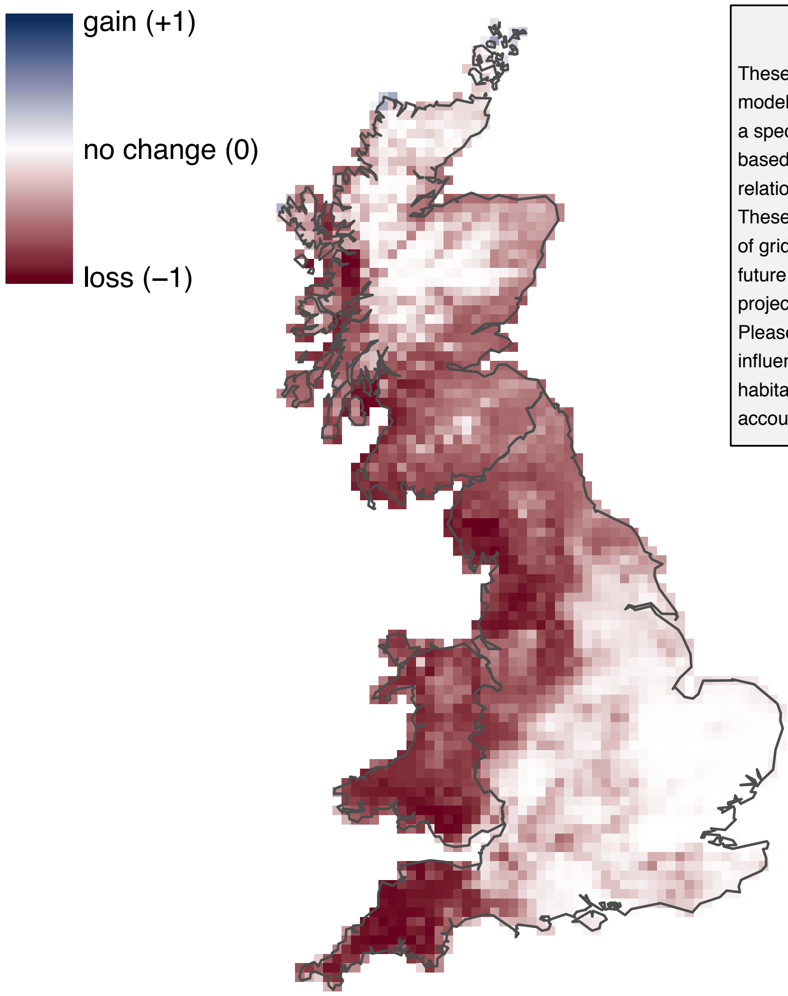
At higher latitudes and altitudes, bilberry responds positively to higher temperatures, if it is not adversely impacted by water deficit (Pato & Obeso 2012; Rixen, Schwoerer & Wipf 2010). It has been demonstrated to benefit from increased CO_2 at the expense of other species (Dawes *et al* 2011).

Although tolerant of wildfire to a certain degree in upland situations, regrowth of bilberry has been shown to be slower than other species found within its habitat, such as heathers, grasses and bracken (Taulavuori, Laine & Taulavuori 2013). The impact of fire is likely to be determined by the timing of the event and the environmental conditions at the time.

Bilberry is not at its northern margin in England, and rarely at its altitudinal limit. There is some scope for it to colonise higher altitudes in parts of the Lake District.

19 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Projected change in potential distribution of bilberry in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015)

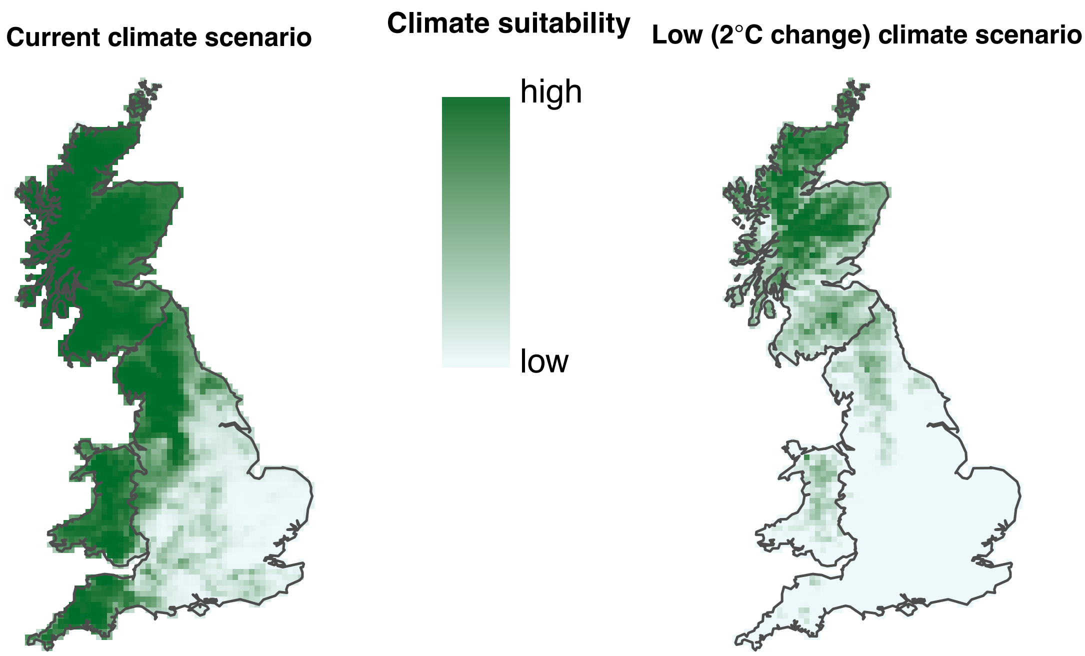


Climate suitability

These maps are created using statistical models which describe the probability that a species will be found in a 10 km grid square, based on its current distribution and its relationship to a number of climatic variables. These can be used to model the suitability of grid squares for a species under possible future climates when climate change projections are taken into account. Please note that other variables that influence species distributions, such as habitat and land–use change, are not accounted for in the modelling process.

Confidence of change

This species was not included as part of Natural England's Research Report NECR175 assessing the risks & opportunities for species in England as a result of climate change, so no assessment of confidence has been made for this species



Created by:	University of York	Created for:	Natural England	Created on:	August 19 2016

Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

Adaptation for bilberry is likely to focus on creating optimum habitat conditions for its growth and reproduction. The main aim in many places will be to ensure grazing is at a level compatible with restoring or maintaining the habitat. Management of woodlands where bilberry is a component of the ground layer should be planned so as to maintain appropriate levels of shade and humidity.

- Manage livestock through low intensity seasonal grazing to promote the growth of bilberry and reduce competition from surrounding vegetation.
- Manage trees and woodland to provide intermediate levels of shade in locations where bilberry populations are declining or are in competition with heather. Seek to retain appropriate canopy cover to maintain high levels of humidity and avoid rapid and excessive opening up of gaps in the canopy where this may encourage the growth of dense bramble.
- In lowland woodlands in particular, seek to control the spread of competing species which may cast high levels of shade such as holly *Ilex aquifolium*, rhododendron *rhododendron ponticum* and shallon *Gaultheria shallon* (the aim for the last two species should be for eradication).
- Manage fire risk and reduce the amount of planned fire management. Follow the **heather and grass burning code**.
- Control the dominance of bracken *Pteridium aquilinum* where it poses a threat to the survival of bilberry through excessive shading and accumulation of leaf litter.
- In the south and east of its range, identify locations that are likely to remain cooler in the face of warming and ensure that they are protected and managed to support bilberry.

Relevant Countryside Stewardship options

LH1 Management of lowland heathland

LH2 Restoration of forestry and woodland to lowland heathland

LH3 Creation of heathland from arable or improved grassland

UP3 Management of moorland

WT10 Management of lowland raised bog

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Bluebells under oak and hazel coppice woodland
© Natural England/Peter Roworth

Bluebell *Hyacinthoides non-scripta* (L.) Chouard ex Rothm.

Climate Change Sensitivity:	HIGH	Ability to Manage:	MEDIUM
Non climatic threats:	MEDIUM	Vulnerability:	MEDIUM

Summary

Bluebells are an inconic part of British woodland ground flora, blooming in the spring, often in large numbers. It is a species which has a well defined oceanic temperate distribution within Europe. While it does not presently reach its southern range margin in the UK it may be at significant risk from climate change in southern and central England.

Description

The bluebell is a member of the lily family with distinctive violet/blue flowers. It is perennial, overwintering as a bulb and emerging in the spring to flower, typically in April to early May. By mid-summer, the foliage and flowers die back completely. *H. non-scripta* freely hybridises with the non-native *H. hispanica*, which presents a threat to the true native species.

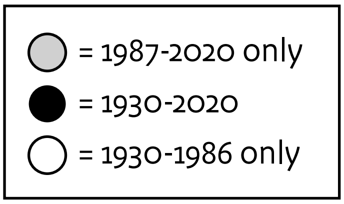
Ecology and distribution

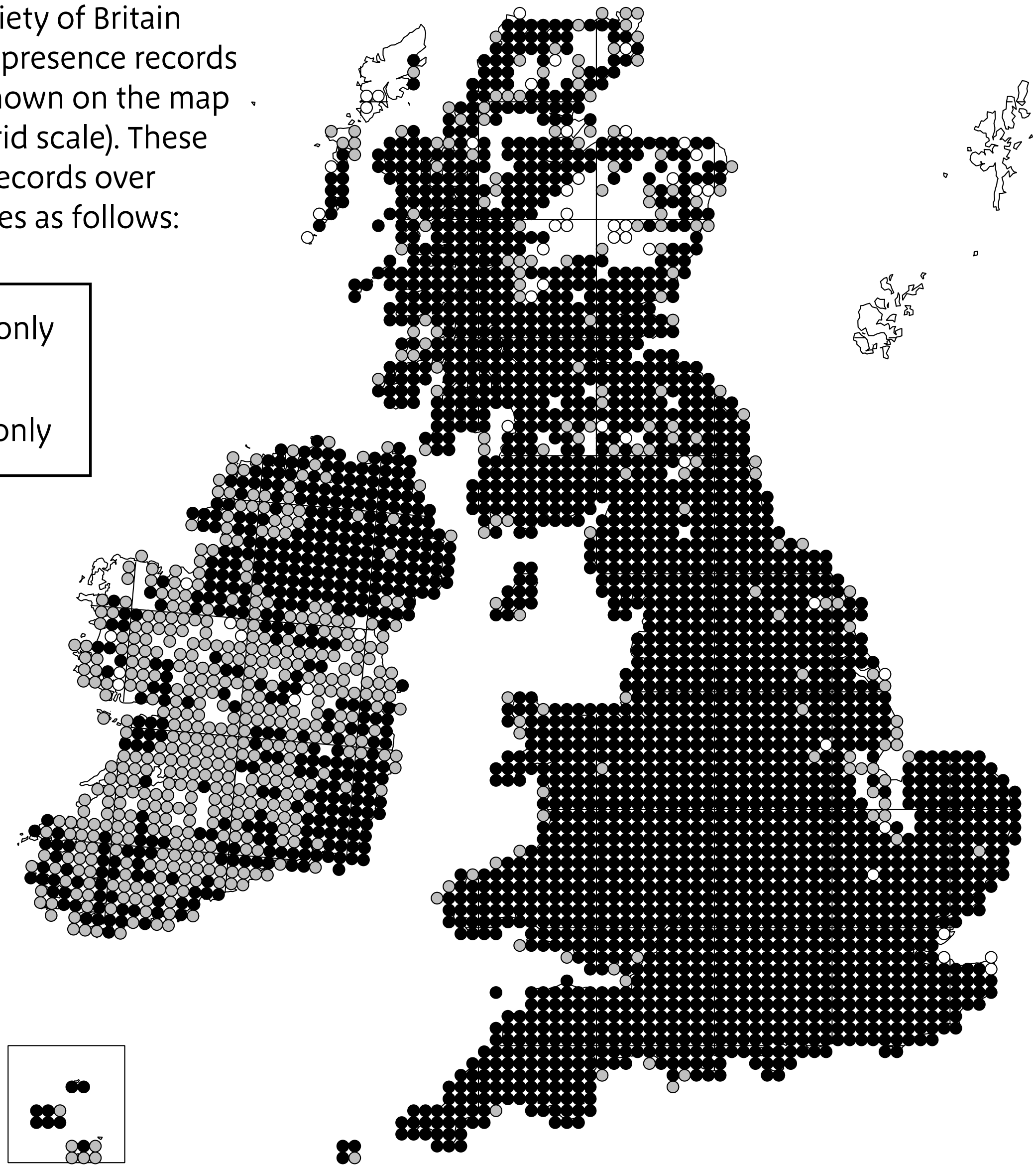
Bluebells occur typically in well drained, deciduous woodland, especially coppice, where they may dominate the ground flora, but can also be found in more open habitats. They are found in most parts of Great Britain except the highest mountains and fenland areas around The Wash. At a European scale, they have a temperate oceanic distribution (Preston & Hill 1997) and are strongly associated with north western areas of Europe with mild, maritime climates. The British Isles contain the largest populations of the species. It occurs on a range of soil types from calcareous to mildly acidic, but is not usually found on very thin soils. There is some evidence that it is drought sensitive (Blackman & Rutter 1954) and more abundant in areas with high rainfall (Kohn *et al* 2009). Seed germination occurs in the autumn and requires a high temperature conditioning phase, with an optimum at 26 to 31 °C, followed by a germination phase at 11 °C (Thompson & Cox 1978).

While the bluebell is an important element of the woodland ground flora, it can grow in both sun and shade conditions and also occurs in grassland, particularly where there is high rainfall and low nutrient conditions (Blackman & Rutter 1954).

Presence of bluebell records at 10km² scale provided by the BSBI and are based on records collected mainly by BSBI recorders.

The Botanical Society of Britain and Ireland (BSBI) presence records for Bluebell are shown on the map opposite (10km grid scale). These are displayed as records over different time slices as follows:





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Confidence in climate change impacts[20]

Distribution change: **MEDIUM CONFIDENCE** Mechanism: **LOW CONFIDENCE**

The distribution of the bluebell reflects a clear climatic pattern. Projections (see map below) indicate that there is likely to be a shift in the area of suitable climate, with large parts of southern and central England becoming unsuitable under 2 °C of warming. The distribution of the bluebell is likely to be related to both temperature and rainfall. Increasing temperatures and more frequent summer drought could both make conditions less suitable for the species. There is a range of potential mechanisms, although these have not been tested:

- Drought in spring and early summer may reduce growth and stop accumulation of sufficient reserves in bulbs.
- Earlier leafing of the tree canopy may reduce the potential for carbon acquisition, as while the bluebell's phenology is sensitive to temperature and it can leaf earlier in warm years, day length is shorter earlier in the spring.
- In some years, maximum temperature thresholds for germination may be exceeded.

To date, there is no evidence of any change in range or decline of individual populations in ways consistent with climate change impacts. There is, however, evidence of flowering advancing in a manner consistent with warmer spring temperatures (Tansey *et al* 2017).

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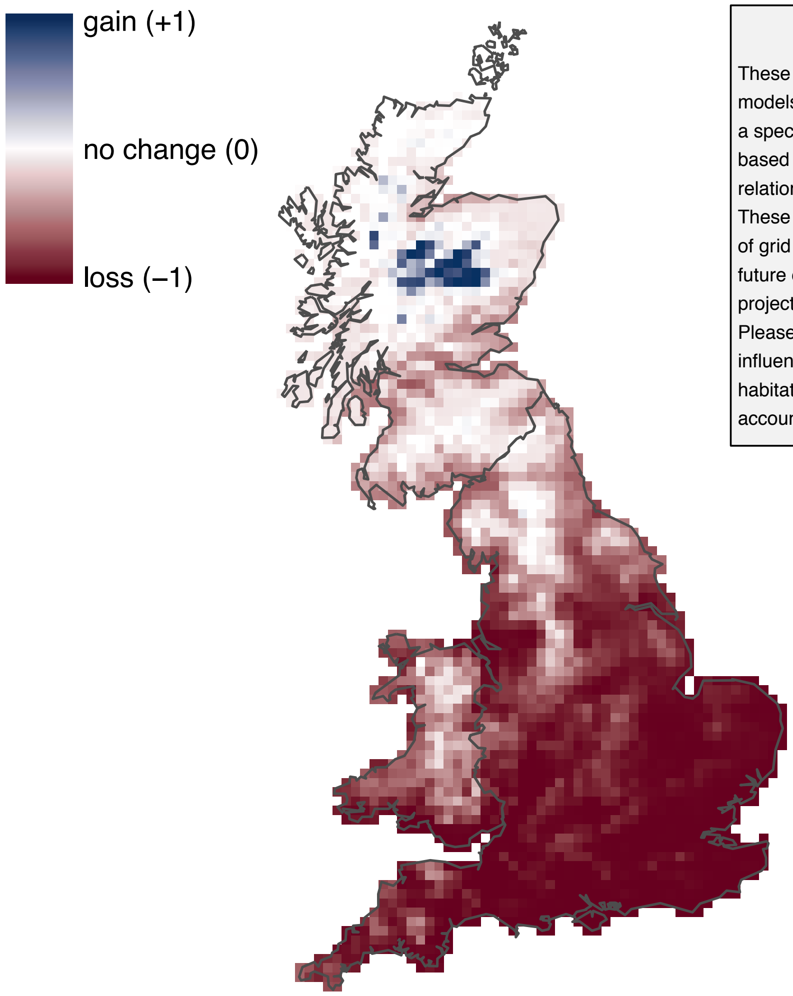
20 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Projected change in potential distribution of bluebell in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015)

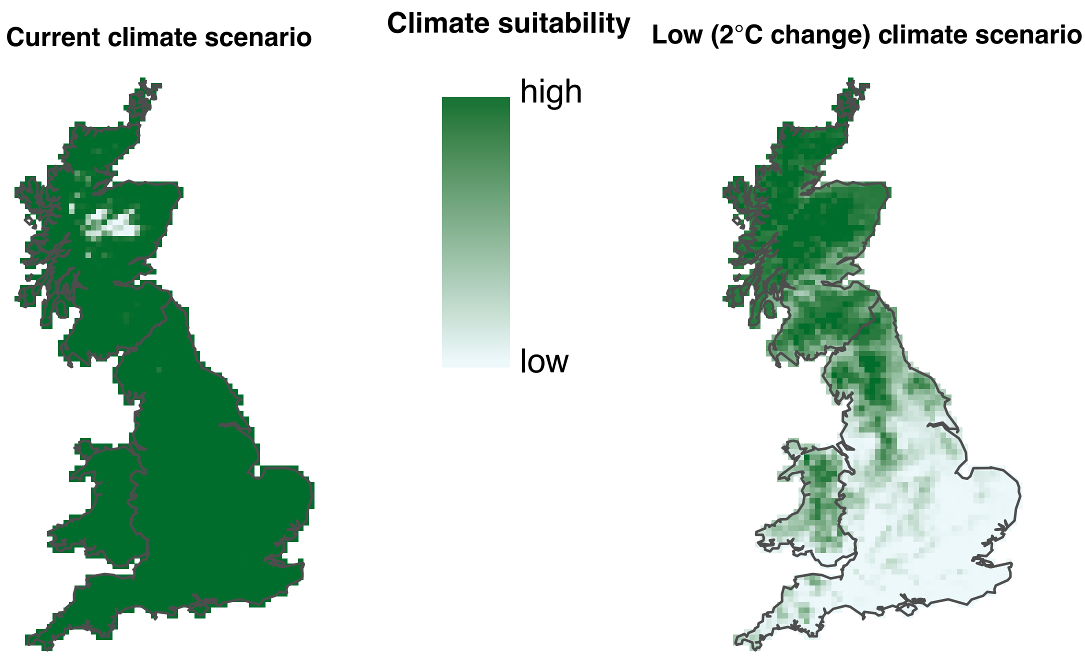


Climate suitability

These maps are created using statistical models which describe the probability that a species will be found in a 10 km grid square, based on its current distribution and its relationship to a number of climatic variables. These can be used to model the suitability of grid squares for a species under possible future climates when climate change projections are taken into account. Please note that other variables that influence species distributions, such as habitat and land–use change, are not accounted for in the modelling process.

Confidence of change

This species was not included as part of Natural England's Research Report NECR175 assessing the risks & opportunities for species in England as a result of climate change, so no assessment of confidence has been made for this species



Created by:	University of York	Created for:	Natural England	Created on:	August 18 2016

Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

Adapting management to conserve woodland habitat in which bluebell is found is the most important aspect of adaptation for this species and the woodland habitat sections should be consulted: the following are supplementary notes from a species specific perspective.

At this stage, the best adaptation options to build resilience of existing populations are not clear, but there are likely to be local refugia – areas which are damper and cooler where the species can survive even in a warmer climate in the southern and central areas. It is also possible that interactions with forest stand structure may help to maintain species *in situ*. For example, a more open canopy may reduce the impacts of earlier leafing. Enlarging woodland patches through strategic planting around the edge will help to keep the core area wetter (as water loss is higher at forest edges) and may reduce the impacts of droughts. Annual monitoring of populations in contrasting places and with different management will help to clarify the best strategies.

Bluebell populations in the north and west of England will become crucial to maintaining the status of the species, not just in England but internationally, given the limited global distribution. Climate change is a threat not just to southern British populations but also to populations in France, Spain and Portugal. It is therefore particularly important to protect these populations from other pressures, such as deer, nitrogen deposition and hybridisation with *H. hispanica*.

Relevant Countryside Stewardship options

WD1 Woodland creation - maintenance payments

WD2 Woodland improvement

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Common green grasshopper
© J. P. Martin

Common green grasshopper *Omocestus viridulus* L.

Climate Change Sensitivity:	HIGH	Ability to Manage:	MEDIUM
Non climatic threats:	MEDIUM	Vulnerability:	MEDIUM

Summary

The common green grasshopper's preference for taller swards in damper localities, together with apparent declines in the east and south of the country, suggest that it is sensitive to summer drying. Adaptation is likely to focus on ensuring its favoured habitat is maintained in areas likely to be less affected by changes in rainfall, especially in the uplands and other areas where topography and hydrology will promote cooler, wetter conditions.

Description

The common green is Britain's most widespread grasshopper species. It is mostly green, but may have brownish sides. It is medium sized, typically 14-23 mm long. It is winged and flies well, but wings never exceed the end of the body. It has a characteristic long, loud song. The females have longer wings and a noticeably long ovipositor, which helps distinguish it from similar species.

Ecology and distribution

The common green grasshopper is a generalist species of unimproved grassland. It prefers taller, damper grassland and feeds on a range of common, abundant grasses, including cocksfoot *Dactylis glomerata*, bent grass *Agrostis* spp, sweet vernal grass *Anthoxanthum odoratum*, rye grass *Lolium* spp., and Yorkshire fog *Holcus lanatus* (Cottam 1985). It is relatively widespread and common in the uplands, but has declined in the lowlands, particularly in the south and east.

It is the first of the grasshoppers to appear, in late spring and early summer. Nymphs can be found from April or May. After several moults, they reach adulthood in June or July, with adults surviving until November. Females lay eggs in the top layer of soil near the base of grass stalks in late summer.

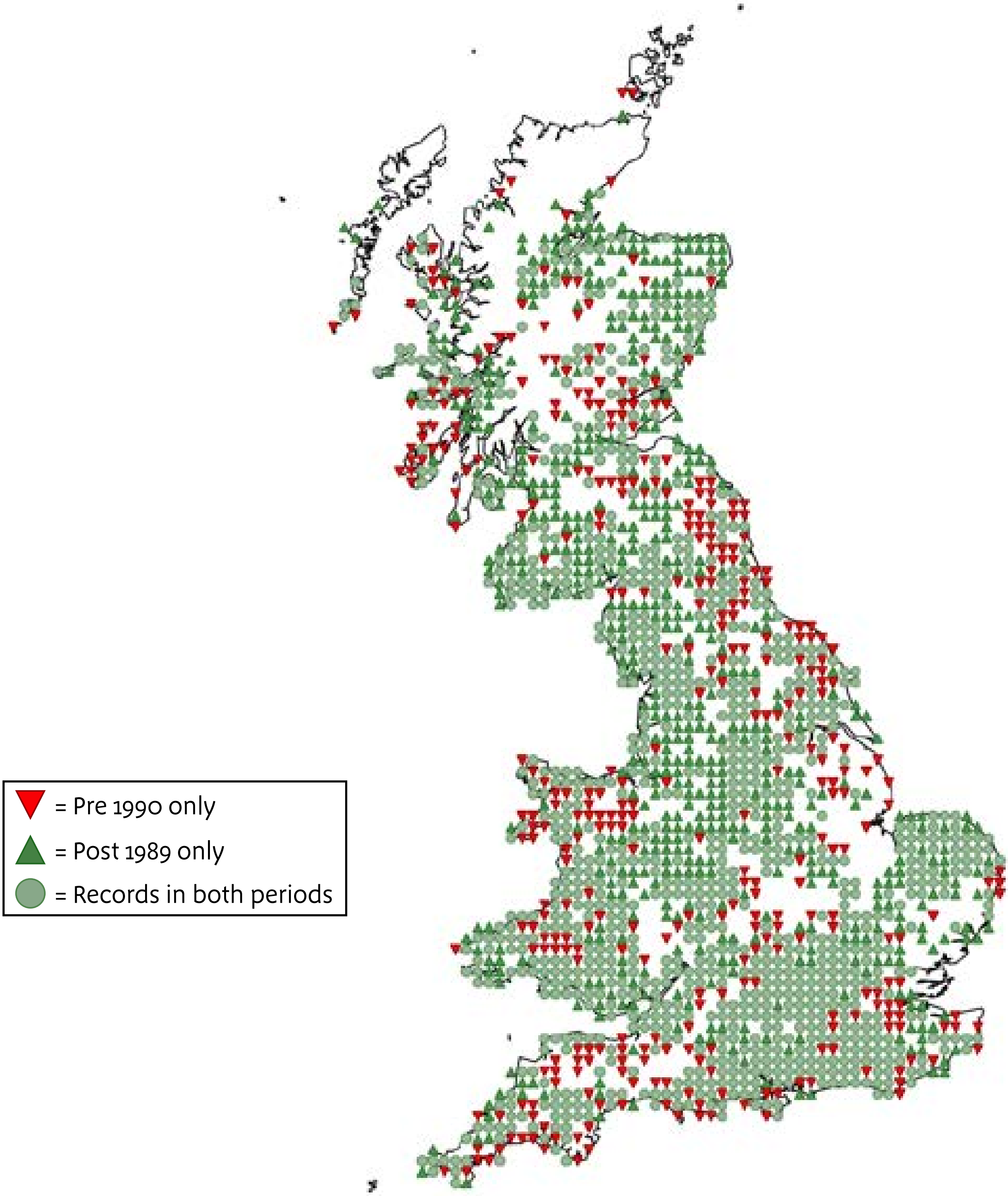
Although the common green grasshopper requires warm conditions (Willott & Hassall 1998), it has less ability to tolerate extreme high temperature than other species, and it will exhibit shade-seeking behaviour if exposed to warm conditions, avoiding short swards because of the danger of overheating (Willott 1997). It is also more tolerant of cooler conditions than other British species of grasshopper (Willott & Hassall 1998) and has an ability to raise its body temperature when it gets cool (Willott 1992).

It is still relatively common but has suffered declines in the lowlands. This is due in part to the loss and intensification of its preferred semi-natural grassland habitat, but climate change is also thought to be contributing to declines. Its local distribution in the south is associated with clay soils rather than more free draining soils (Gardiner 2010).

Its generalist grazing behaviour has been suggested as a mechanism for influencing the species richness of grassland (Branson & Sword 2009). Accordingly, its loss from its lowland grassland sites may in turn lead to changes in the floral composition.

The Grasshopper Recording Scheme and additional National Biodiversity Network presence records for common green grasshopper pre- and post-1990 are shown on the map below (10km grid scale). (See **www.orthoptera.org.uk** and **NBN Atlas terms and conditions**, and Appendix 1 for the list of NBN datasets included). The grasshopper recording scheme does not regularly cover all squares. Gains and losses of individual squares should not be over-interpreted as they may be due to changing recording patterns.

Presence of Common green grasshopper records, 10x10km grid.
Grasshopper Recording Scheme and NBN Atlas.



It is likely that the common green grasshopper has seen a net increase in distribution in Scotland (from 285 squares before 1990 to 421 squares after 1989, a 48% rise). In contrast, the species has seen much smaller net increases in England (from 835 to 920 squares, a 10% rise) and Wales (from 190 to 209 squares, a 10% rise). Considering a large increase in recording effort over time it is likely that these changes reflect at best a stable distribution in England and Wales (Beckmann *et al* 2015).

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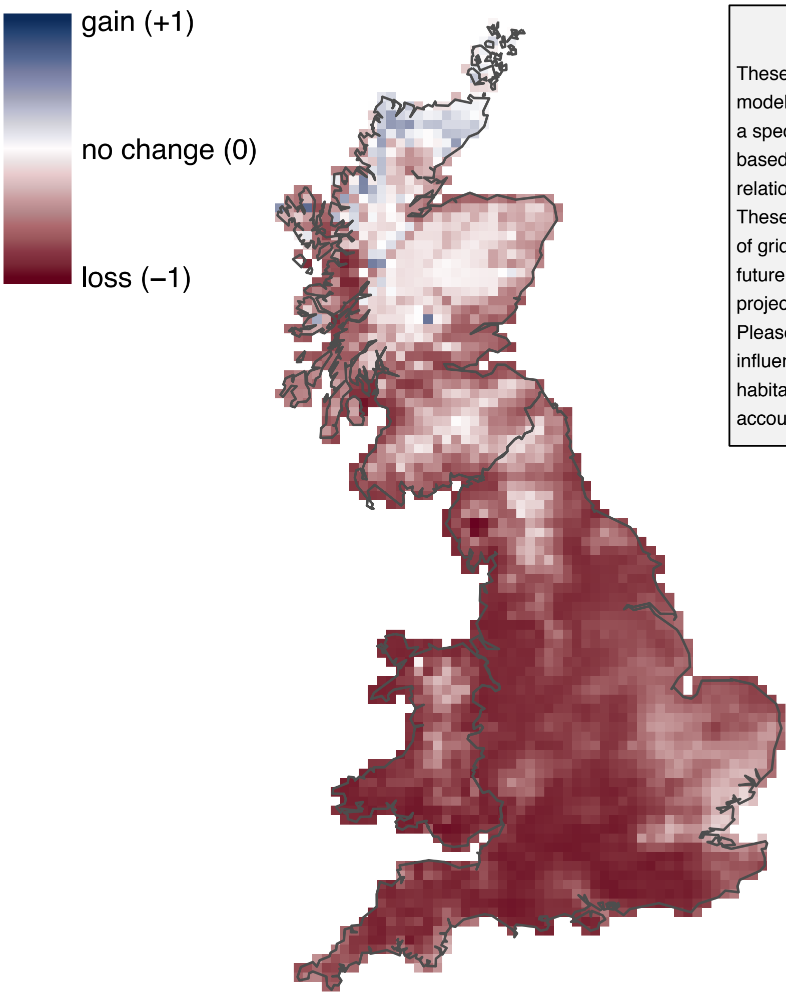
Confidence in climate change impacts[21]

Distribution change: **LOW CONFIDENCE** Mechanism: **LOW CONFIDENCE**

The threat to the common green grasshopper from climate change can be inferred through modelling its climate envelope and its preference for taller swards in cool, damp locations. Indications of a possible decline in the south and east of England, the parts of the country that are experiencing the greatest increases in summer drying and warming, suggests that climate change may be a contributory factor.

21 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Projected change in potential distribution of common green grasshopper in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015).

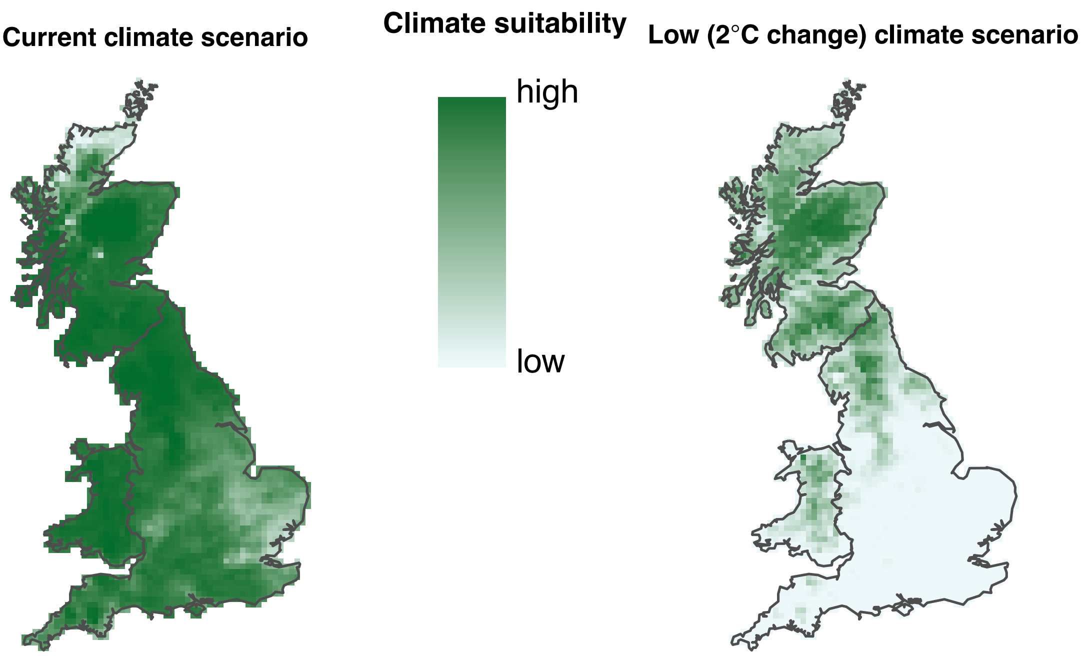


Climate suitability

These maps are created using statistical models which describe the probability that a species will be found in a 10 km grid square, based on its current distribution and its relationship to a number of climatic variables. These can be used to model the suitability of grid squares for a species under possible future climates when climate change projections are taken into account. Please note that other variables that influence species distributions, such as habitat and land–use change, are not accounted for in the modelling process.

Confidence of change

An assessment of the available data and other factors, as part of Natural England's Research Report NECR175, suggests that our confidence in this projection is very high. N.B. many confidence assessments are rated as low because there is a lack of published information on the likely influence of climate on the species concerned.



Created by:	University of York	Created for:	Natural England	Created on:	August 18 2016

Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

Site management is not usually tailored to currently widespread invertebrate species, like the common green grasshopper; however, ensuring its persistence, and that of species like it, in southern and eastern England may require some adjustment to management of sites. The common green grasshopper's sensitivity to extreme heat suggests that adaptation should focus on ensuring its favoured habitat is maintained in areas likely to remain least affected by warming. In the lowlands, potential refugial areas where topography and hydrology lead to cooler conditions should be identified and conserved. At sites exposed to hotter, drier conditions, changes to the management of grassland to allow taller swards and create a cooler microclimate should be considered.

- Unimproved grassland in the uplands should be managed to ensure that the grasshopper's core areas are protected.
- On southern and eastern locations and lower lying sites with south-facing topography, grass swards can be maintained at a taller height or have taller elements within them to promote cooler microclimates.
- In some cases, maintaining or restoring the hydrology of sites may help to ensure the ongoing presence of cooler, damp habitats that it prefers.
- In southern and eastern areas, habitat creation can be used to increase topographic variation in available grassland, creating a diversity of microclimates.
- Monitoring will allow population changes in different locations to be identified and quantified.

Relevant Countryside Stewardship options

GS2 Permanent grassland with very low inputs (outside SDAs)

GS5 Permanent grassland with very low inputs in SDAs

GS6 Management of species-rich grassland

GS7 Restoration towards species-rich grassland

GS8 Creation of species-rich grassland

References and further reading

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NBN Atlas occurrence download at https://nbnatlas.org accessed on Thu Apr 20 10:30:45 UTC 2020.

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Eurasian Curlew, Norfolk
© Natural England/Allan Drewitt

Eurasian Curlew *Numenius arquata* Linn.

Climate Change Sensitivity:	MEDIUM	Ability to Manage:	MEDIUM
Non climatic threats:	HIGH	Vulnerability:	HIGH

Summary

The Eurasian Curlew (henceforth 'curlew') is experiencing rapid declines. The main pressures facing curlews in the UK are the predation of eggs and chicks, and habitat loss and degradation through changing farming practices and afforestation of open ground. The threats from climate change are considerable, given that curlews breeding in the UK are increasingly reliant on upland areas, which are sensitive to climate change. Large parts of England are projected to become climatically unsuitable for breeding curlew under a 2°C temperature rise. Efforts should therefore focus on managing predation and improving habitat quality in upland areas, thereby enhancing their ability to cope with climate change impacts.

Description

The Eurasian Curlew is Europe's largest wader, with a wingspan of around a metre and weighing almost a kilogram. They are one of our most iconic birds, with their haunting bubbling calls and long down-curved beaks. Curlews winter around the coasts of Europe and northern Africa, migrating inland to their breeding grounds in spring. They commonly live for 20-25 years and are very site-faithful, often returning to the same field or patch of moorland each spring.

Ecology and distribution

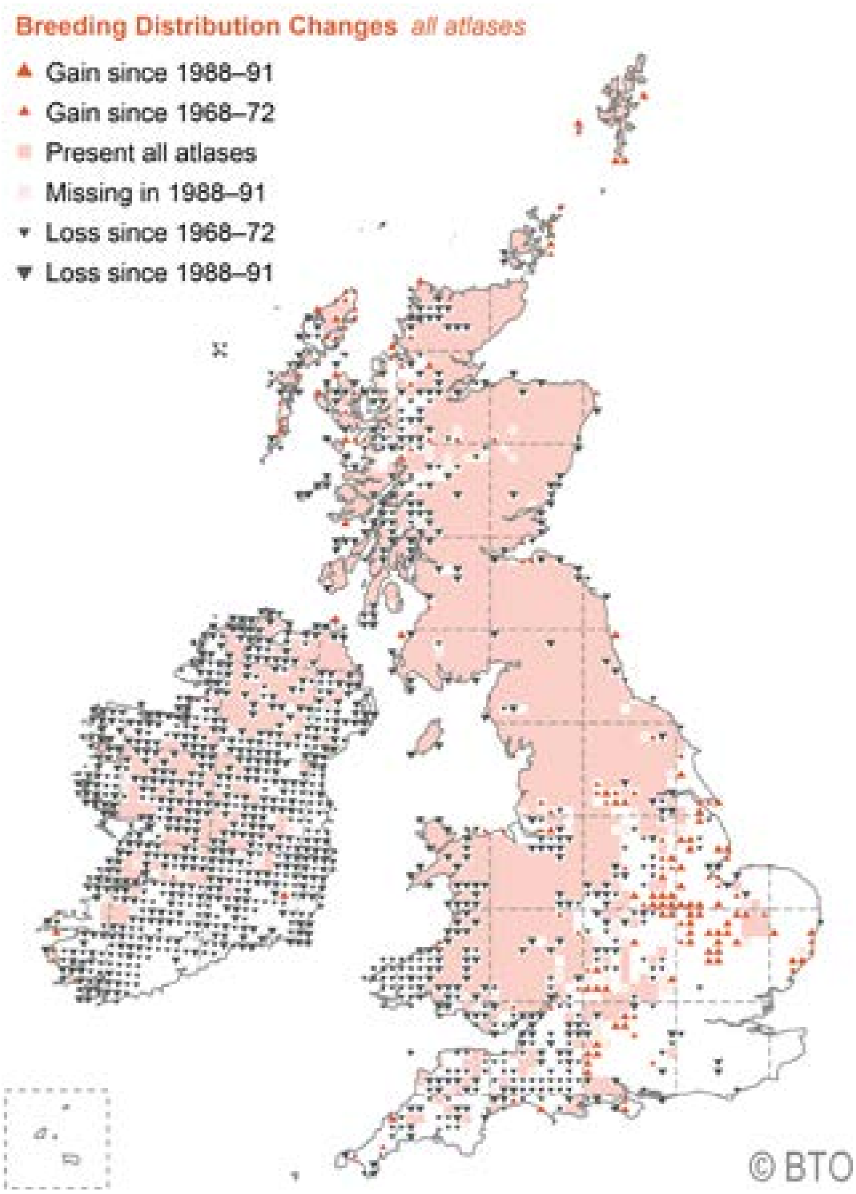
Curlews are in steep decline, and are listed as globally near-threatened by the International Union for Conservation of Nature (IUCN) and as 'red' on the Birds of Conservation Concern (BOCC) list. Between 1995 and 2016 the UK breeding population declined by 48%, with the most severe declines in Wales and Northern Ireland (Robinson *et al* 2016). These declines are due mainly to reduced breeding success, due in particular to nest/chick predation, which may have been exacerbated by historical and ongoing agricultural changes and other impacts on breeding habitat quality, including afforestation and wind farm development (Douglas *et al* 2014; Brown *et al* 2015; Robinson *et al* 2016).

An International Single Species Action Plan has been put in place across Europe (Brown, 2015), and the curlew has been named Britain's highest conservation priority bird species (Brown *et al* 2015). This is due to the rate of recent declines and conservation status of the curlew, and the fact that the UK is of crucial importance to curlew, sustaining up to a quarter of the global population in both summer and winter (Brown *et al* 2015).

Curlews winter mainly in large flocks on intertidal mudflats, coastal grasslands, farmland, and (to a lesser extent) inland wetlands. During March-July, curlews breed in a range of wetland and agricultural habitats, including lowland wet grassland, arable croplands and upland moorland. However, in the UK, recent severe declines in the lowlands mean that most breeding curlew are now concentrated in the uplands of northern England and Scotland (typical population density 1-2 pairs per km^2). Exceptionally high concentrations are found in the Northern Isles of Orkney and Shetland (reaching population densities of around 20 pairs per km^2), where the absence of foxes and a mosaic of lowland agricultural and moorland habitats is likely to be particularly beneficial to breeding curlew (D. Douglas, A. Leitch & S. Sankey pers. comm.).

In the UK, curlews start to lay eggs in mid to late April. An average of four eggs are laid (Austin & Crick 1994), which are incubated for approximately 31 days, with both male and female taking turns. Chicks leave the nest within two days of hatching, and are dependent on their parents for the next few weeks, foraging independently but unable to fly until 5-6 weeks of age.

Historic changes in the distribution of the Eurasian curlew
(reproduced with permission of the BTO, from Balmer *et al* 2013)



Confidence in climate change impacts[22]

Distribution change: **HIGH CONFIDENCE** Mechanism: **LOW CONFIDENCE**

Curlews are expected to show population declines and northward range contractions in response to climate change under a 2°C global temperature rise scenario. Climate envelope modelling suggests that the UK population of breeding curlews could drop by 20-25% (Renwick *et al* 2012), possibly linked to increased summer warming, with more southerly, westerly and lowland populations suffering the worst declines. Under more extreme warming (4°C), the southern range limit is likely to move into northern England, with the English population being restricted to upland areas from the Pennines northwards, and

22 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

southern populations likely to be lost entirely. Analysis of Curlew abundance data suggests that numbers tended to increase and were higher in areas of cooler temperatures and higher summer rainfall (Franks *et al* 2017). The increased frequency of extreme weather events such as drought and flooding could also threaten curlew populations, for instance by destroying nests on flood-prone areas (already an important cause of breeding failure in some studied populations (see refs in Brown 2015), and by reducing food availability e.g. through the seasonal drying-out of blanket bog, or by limiting foraging opportunities.

The abundance of key insect food sources may be altered through climate change, as has been shown for cranefly larvae, which are an important food source for breeding waders in the UK uplands (Pearce-Higgins *et al* 2010), although very little is known about how this is likely to impact on curlews specifically. Climate change could also bring about more subtle impacts, such as longer growing seasons leading to altered cutting and mowing dates for hay and silage, which could affect curlews through various mechanisms, including direct nest destruction, altered predation pressure and disruption to foraging opportunities.

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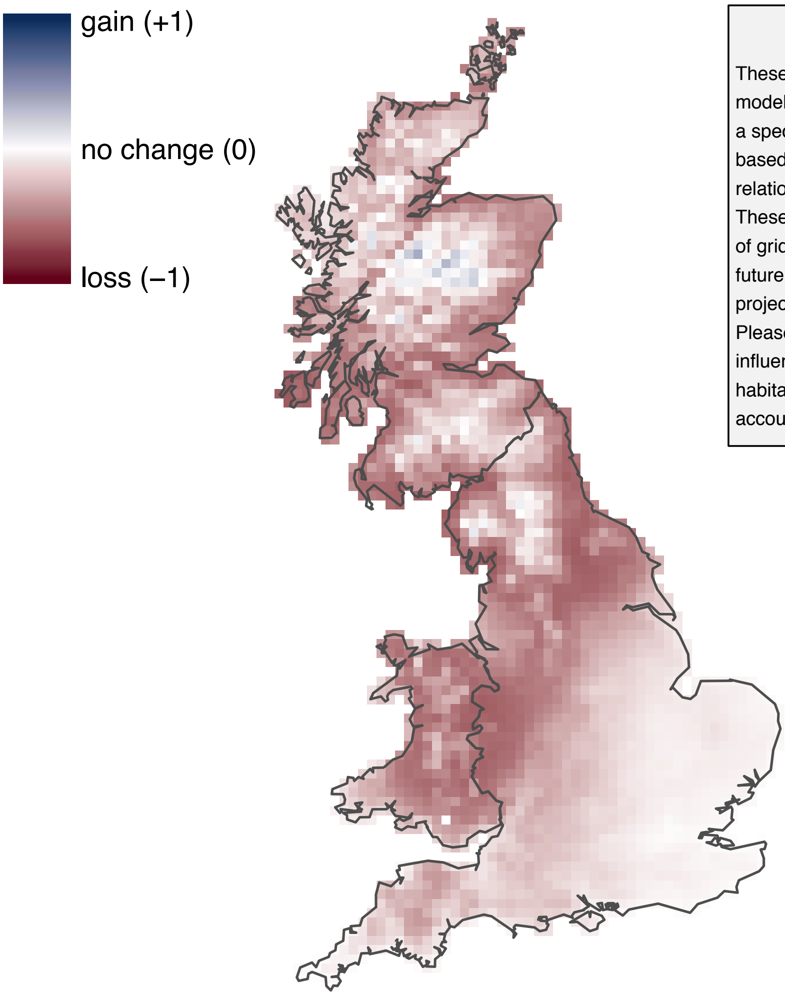
Projected change in potential distribution of curlew in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015)

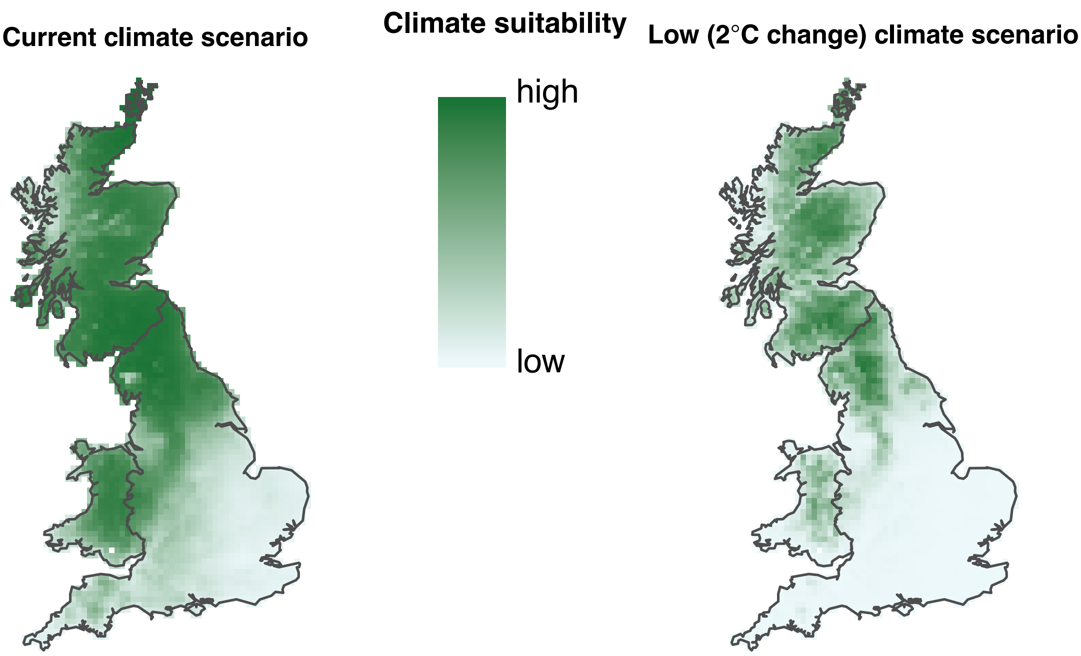


Climate suitability

These maps are created using statistical models which describe the probability that a species will be found in a 10 km grid square, based on its current distribution and its relationship to a number of climatic variables. These can be used to model the suitability of grid squares for a species under possible future climates when climate change projections are taken into account. Please note that other variables that influence species distributions, such as habitat and land–use change, are not accounted for in the modelling process.

Confidence of change

An assessment of the available data and other factors, as part of Natural England's Research Report NECR175, suggests that our confidence in this projection is very high. N.B. many confidence assessments are rated as low because there is a lack of published information on the likely influence of climate on the species concerned.



Created by:	University of York	Created for:	Natural England	Created on:	August 17 2016

Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

Adaptation for the curlew should focus on a combination of habitat restoration and predation management, often at the landscape scale. In terms of habitat management, the most important actions are the maintenance and restoration of a structurally diverse sward and wet areas and reversing the effects of drainage activities by undertaking drain blocking. These will increase the availability of high quality nesting sites, increase foraging opportunities and reduce the susceptibility of the habitats to drying. For other upland breeding waders, it has been suggested that land management which aims to increase the abundance of insect food sources can offer a successful method of mitigating against the impacts of climate change (Pearce-Higgins *et al* 2010), and similar methods are also likely to benefit the curlew.

Predation management should consider lethal control of key nest and chick predators, particularly in areas supporting high numbers of breeding curlew. This may be required as a short-term measure, but also possibly in the longer term. However, solutions must also address the root causes of high generalist predator populations. This could include appropriate siting of forest plantations that support nest and chick predators such as corvids and foxes, ensuring that farming activities minimise the abundance of carrion in the landscape, and giving attention to the role of released gamebirds as a source of biomass for predators.

This combination of habitat and predation management should greatly improve the breeding success of individual pairs, as well as increasing the overall number of breeding pairs able to be supported by a landscape and help buffer curlew populations against the negative impacts of climate change. Several specific habitat management practices that could be considered are listed below:

- Avoid over grazing and under grazing. Maintaining a minimum stocking rate of 0.05 livestock units (LUs) per hectare for a period of 4 months between 1 June and 30 September will avoid the development of rank and excessively dense swards. The exception should be on areas of deep peat or blanket bog, where lower densities may be required to avoid peat damage.
- Graze with cattle, ponies or goats (in preference to sheep) where possible, to ensure that rushes and other tough plant species are grazed and root stocks of dominant species are broken up to prevent infestations. Avoid grazing cattle on deep peat or blanket bog.
- Maintain wetlands, including peat bogs, other mires and hillside flushes. Where possible, remove grips/drains, create wet features such as pools and scrapes, and re-vegetate areas of bare peat.
- Use cutting in preference to burning as a vegetation management tool. If essential, burning should be used only with extreme care (following the Defra Heather and Grass Burning Code) and avoiding peatlands.
- Remove non-native conifers and restore the land to bog or heathland.

In general, efforts should focus on upland areas that currently support the majority of the English breeding population. Remnant populations in lowland areas are likely to face more extreme pressures, both in terms of climatic warming and habitat factors (intensive farming, urban development, human disturbance, etc.). Although their conservation may be more complex in the south and west, conservation actions there may also be open to different opportunities than in the uplands.

Relevant Countryside Stewardship options

Several Countryside Stewardship options exist for lowland and upland marginal farmland and moorland that are likely to offer benefits for breeding curlew, and thus should help reduce potential negative impacts of climate change. The most relevant options are listed below:

GS2 Permanent grassland with very low inputs (outside SDAs)

GS5 Permanent grassland with very low inputs in SDAs

GS6 Management of species-rich grassland

GS7 Restoration towards species-rich grassland

GS9 Management of wet grassland for breeding waders and wildfowl

GS13 Management of grassland for target features

GS15 Haymaking supplement

UP1 Enclosed rough grazing

UP2 Management of rough grazing for birds

UP3 Management of moorland

UP4 Management of moorland vegetation supplement

UP5 Moorland re-wetting supplement

WN1 Grip blocking

Case Study

Blanket bog restoration at Dove Stone RSPB reserve

Since 2010, a partnership between RSPB and United Utilities has been restoring 2,500 hectares of degraded peatland at the 4,000 ha RSPB Dove Stone reserve in the Peak District National Park. Working with tenant farmers, the project involved re-vegetating bare peat, blocking eroded gullies to hold water back and slow flows, and planting over 300,000 individual handfuls of peat-forming *sphagnum* moss. The work is ongoing, but there have been increases in breeding dunlins, golden plovers, curlews and red grouse. For curlew, the population has increased from 35 to 42 pairs between 2010 and 2014, and it is hoped that these actions will help make such populations of curlew more resilient to climate change.

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Dartford warbler
© Ben Hall (rspb-images.com)

Dartford Warbler *Sylvia undata* Boddaert

Climate Change Sensitivity:	POTENTIAL BENEFIT	Ability to Manage:	MEDIUM
Non climatic threats:	MEDIUM	Vulnerability:	LOW

Summary

The Dartford warbler reaches the northern limit of its range in the UK and is highly sensitive to cold winters. Recent climatic warming is benefitting the species in England, driving an expansion of both its range and population size. Across its full European range, climate change poses a threat, with substantial losses in the climate suitability in its core areas of France and Spain. The UK will therefore become more important for the conservation of this species in Europe. Ensuring the optimum management and protection of its core sites and facilitating its spread through habitat restoration and creation in new areas of climate suitability are the key adaptation responses.

Description

The Dartford warbler is a small, dark warbler, distinguished from other UK warblers by a long thin tail that it often cocks upwards like that of a wren, and the fact that it is one of only two warbler species to spend the whole year in this country. It frequently perches on top of gorse bushes to sing, and is often seen flying between the gorse.

Its plumage blends in with the vegetation of its preferred heathland habitat. The adult male has darkish grey upper parts and has dull wine-red colouration below, except for the centre of the belly which has an off-white patch. Its red eye-ring is striking. The sexes are similar, but the adult female is usually less grey above and paler below. Juvenile birds are similar to females, or even browner.

Ecology and distribution

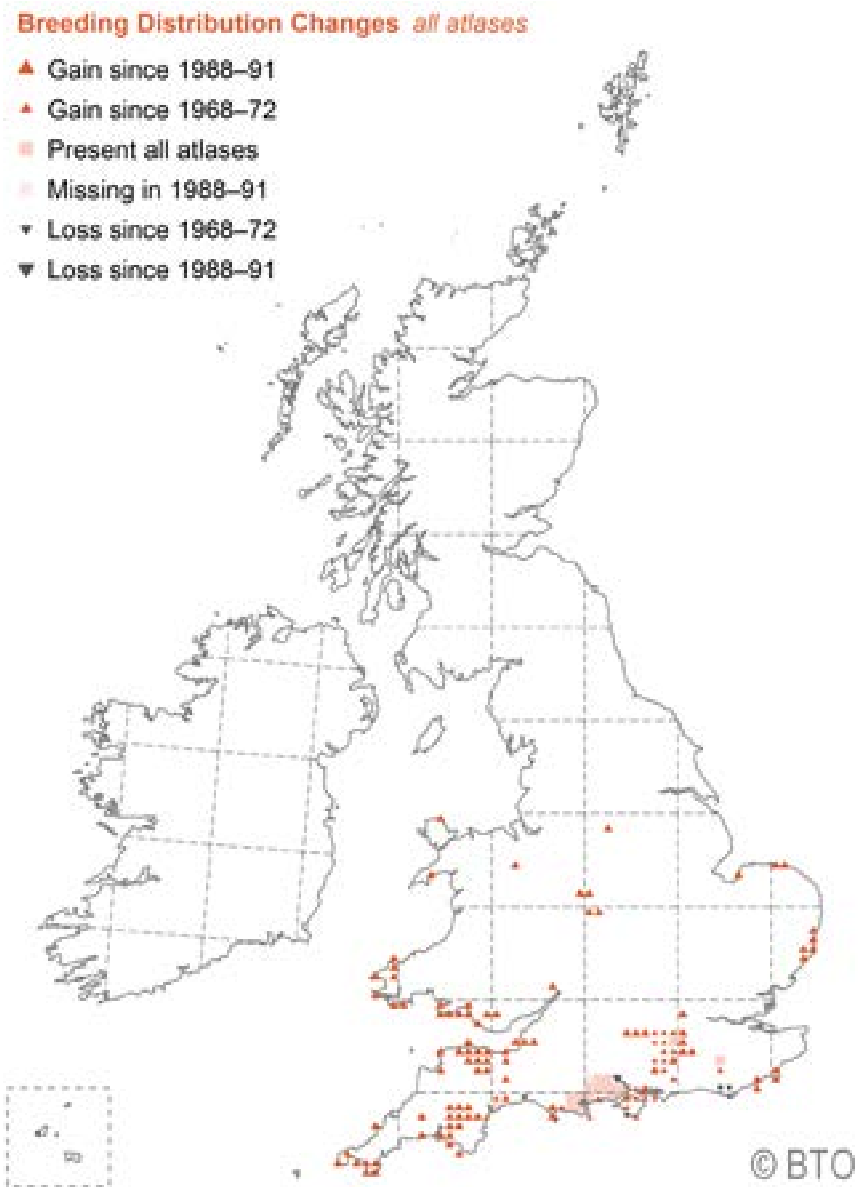
Unlike many warblers in England, the Dartford warbler is a resident. It is mainly found on heathland in the south and east of the country. The bird is territorial, favouring gorse dominated heathland (van der Berg *et al* 2001). The birds typically nest in gorse *Ulex europaeus* or common heather *Calluna vulgaris*. The nest is a compact cup-shape, usually located in dense bushes within 60 cm of the ground. Eggs are laid from mid-April in southern England. Chicks are fed on invertebrates by both parents. Fledging takes 10–14 days and the young are fed by their parents for up to a further two weeks. Two, and occasionally three, broods are raised in a year.

Gorse is the preferred habitat in England where it is present (Bibby 1979a) as it provides the majority of the bird's invertebrate food. In Europe, the Dartford warbler is a species of relatively early successional heathland and low Mediterranean scrublands (Cantos & Isenmann 1997), being able to colonise within two years of fire (Pons *et al* 2012). An increase in scrub and woodland reduces the habitat suitability (Pons *et al* 2012; Regos *et al* 2015).

The bird reaches the northern limit of its European range in the UK (Huntley *et al* 2007). Historically it was broadly distributed across the southern UK, stretching up into the Midlands (Holloway 1996). In the second half of the 20th century it suffered a considerable decline associated with the loss or degradation of its heathland habitat. Superimposed on this were periodic population crashes associated with severe winters (Bibby 1979b; Gibbons & Wotton 1996). The Dartford warbler has the ability to recover rapidly following population crashes due to repeated nesting and a high survival rate for the young. The birds are prone to human disturbance when nesting in heather (Murison *et al* 2007) and show an element of avoidance of small fragmented sites and those in close proximity to woodland, intensive agriculture and urban areas (van der Berg *et al* 2001).

Since the 1980s, it has extended its range northwards, colonised additional sites within its current range, and spread to additional sites to the east and west and at higher altitudes (Thomas *et al* 2012; Bradbury *et al* 2011). Colonisation of sites is more likely in landscapes containing protected areas (Gillingham *et al* 2015) than in landscapes with fewer designated sites.

Historic changes in the distribution of the Dartford warbler
(reproduced with permission of the BTO, from Balmer *et al* 2013)



Confidence in climate change impacts[23]

Distribution change: **HIGH CONFIDENCE** Mechanism: **HIGH CONFIDENCE**

Climate change projections suggest that the suitable climate space for the Dartford warbler will expand considerably within England and Wales, which aligns with the current range expansion. The latest national survey in 2006 showed that the population had increased from ten after the 1962/63 winter, to 3,214 territories in England and Wales, with range expansions in the southwest and in East Anglia and a few records from Staffordshire and West Midlands (Wotton *et al* 2009). Newly colonised sites tended to be on steeper, more south-facing slopes than previously colonised sites, and some were at higher altitudes than previously, suggesting that climate change has been influential in its range expansion (Bradbury *et al* 2011).

23 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

In England, Dartford warbler populations suffer dramatically in extremely cold winters. Following the severe winters of 1961/63, the breeding population collapsed from 450 pairs to just 10. More recent cold winters have had an adverse impact, but have not been sufficiently cold to influence the long-term population trend (Palmer *et al* 2017). Dense gorse has been shown to afford some level of protection during periods of extreme cold. Unlike heather, it is able to maintain shelter and access to food beneath the canopy during periods of snow (Clark & Eyre 2012).

Recovery of populations from cold events is most rapid on heathland compared to sub-optimal habitats such as woodland (Jiguet & Williamson 2013), which are then recolonised once the core populations have recovered.

The Dartford warbler is vulnerable to the loss or degradation of habitat due to wildfire and inappropriate fire management regimes (Regos *et al* 2015). The species is also sensitive to the impact of drought impacting the food supply of juveniles (Bibby 1979b); a threat likely to become more prevalent, especially on sites in the south and east of England. Its sensitivity to human disturbance may also be important if warmer summers lead to increased recreational use of their breeding grounds.

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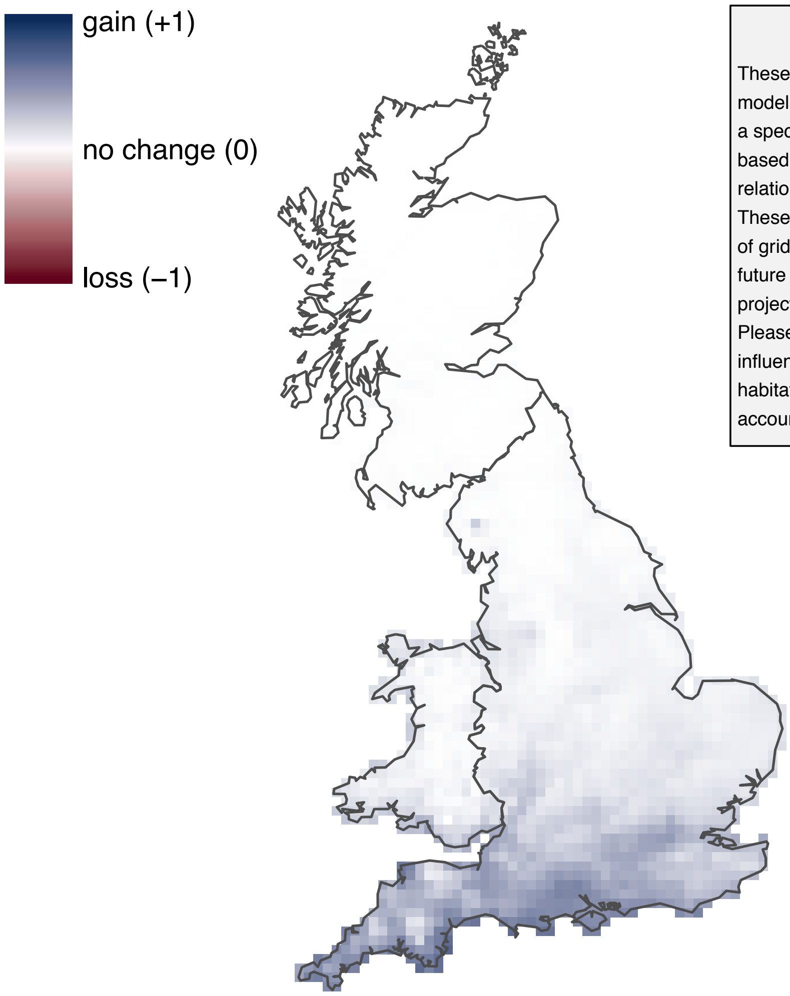
Projected change in potential distribution of Dartford warbler in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015).

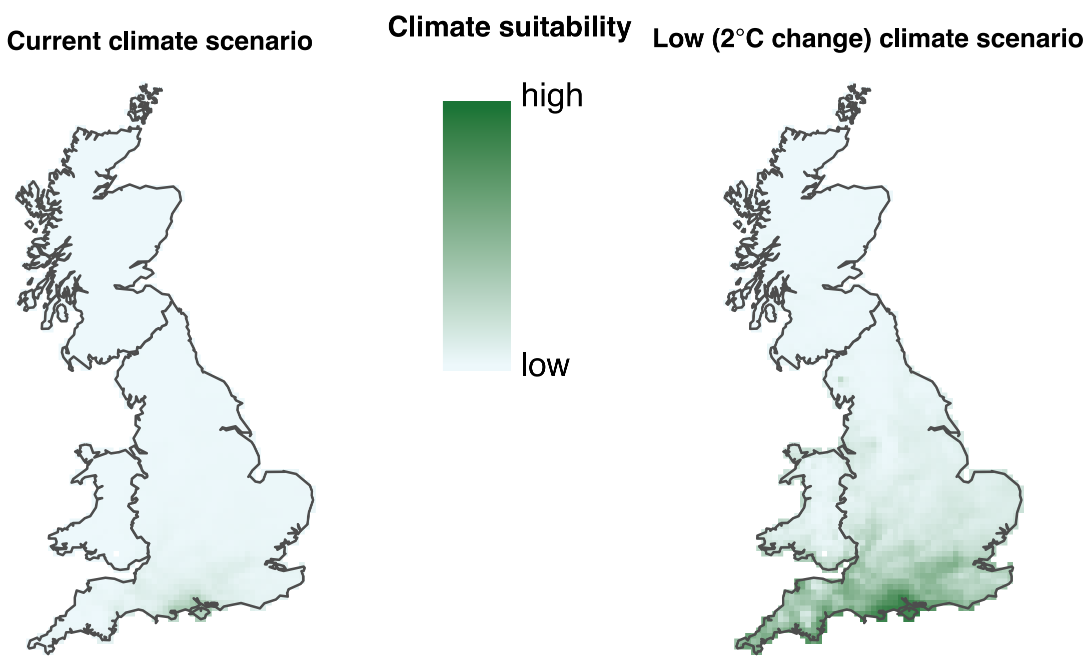


Climate suitability

These maps are created using statistical models which describe the probability that a species will be found in a 10 km grid square, based on its current distribution and its relationship to a number of climatic variables. These can be used to model the suitability of grid squares for a species under possible future climates when climate change projections are taken into account.
Please note that other variables that influence species distributions, such as habitat and land–use change, are not accounted for in the modelling process.

Confidence of change

This species was not included as part of Natural England's Research Report NECR175 assessing the risks & opportunities for species in England as a result of climate change, so no assessment of confidence has been made for this species



Created by:	University of York	Created for:	Natural England	Created on:	August 17 2016

Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

- Ensure optimum management on existing sites, including the promotion of patches of dense gorse of around 0.5-1.5 m in height and minimising disturbance.
- Where possible, expand the area of suitable habitat within existing heathland sites through the reduction of woodland and scrub, while conserving gorse, and in fragmented landscapes seek to link up patches of suitable habitat.
- On drought affected sites, especially in the south and east, address factors that adversely affect hydrology.
- Within a landscape, identify core areas and ensure appropriate management is in place. These areas may be based on the presence of suitable habitat, or topography that leads to a warmer microclimate and where the hydrology means it is less susceptible to drought. These will remain important refugia during extreme events.
- Consider creating, restoring and managing heathland adjacent or close to existing sites.
- In upland areas, particularly on south-facing slopes, create and manage suitable areas of heathland habitat, especially tall gorse and heather, and remove conifers.
- Put in place fire management contingency planning, especially in the drier heaths of the south and east.
- Put in place access controls on sensitive sites to avoid disturbance of breeding pairs.
- Ensure sufficient flexibility of management to enable winter operations to be undertaken within a shorter operation window, and during possible extreme weather events.
- Adjust conservation goals and objectives, particularly in northern sites, to reflect expanding populations and the increasing importance of the UK for the species.

Relevant Countryside Stewardship options

LH1 Management of lowland heathland

LH2 Restoration of forestry and woodland to lowland heathland

LH3 Creation of heathland from arable or improved grassland

Case Studies

In order to encourage the expansion of Dartford warblers in southern England, in 2002 the RSPB bought 164 ha of commercial conifer plantation at Farnham Heath in Surrey. A small (<5 ha) area of heath immediately adjacent, managed by the Amphibian and Reptile Conservation Trust, held good numbers of sand lizards, but was too small and isolated to support Dartford warblers.

The land was former heathland with good potential for restoration, and following an Environmental Impact Assessment process, felling began in 2004 to remove most of the plantation. This continued in phases until 2014, with just over 100 ha of heathland currently restored.

Regeneration of heather from the seedbank was excellent, so there was no need to import seed or turf. Common gorse regeneration, however, was patchy. Attempts to transplant seedlings from elsewhere on the reserve, or to grow gorse from seed and plant it out, have not been especially successful.

Dartford warblers first bred on the reserve in 2015, and had increased to five pairs by 2017. Woodlarks, nightjars, tree pipits and stonechats all breed on the restored heathland, as do silver studded blue and grayling butterflies, and sand lizards have spread from their isolated refuge to colonise the expanded heath.

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Forester *Adscita statices*
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The Forester *Adscita statices* Linnaeus.

Climate Change Sensitivity:	MEDIUM	Ability to Manage:	MEDIUM
Non climatic threats:	HIGH	Vulnerability:	MEDIUM

Summary

The forester has been in decline across all of its range since the mid-20th century. The main reason for this decline has been agricultural intensification of its open grassland habitat, and abandonment leading to the encroachment of scrub and trees. Modelling suggests that the climate suitability for the species will decline across much of England. The impact of climate change is likely to operate through the degradation of its preferred habitat of unimproved wet or damp grassland. Because it has relatively poor dispersal, adaptation is likely to focus on ensuring the optimum management of existing sites and the restoration and creation of semi-natural grassland in close proximity to existing colonies.

Description

The forester is a metallic green, medium sized moth. It is the most common and widespread of the three forester species seen in England, and with a wingspan of 2.5-2.8 cm it is also the largest. Like the other Burnet moths, it is day flying. It can be separated from the similar cistus forester *Adscita geryon*, which only occurs on limestone districts where common rock-rose is found, by its larger wingspan. The caterpillar is pale yellow-green and has a dark dorsal stripe. It also has fine white hairs on its back.

Ecology and distribution

The forester is found in a range of habitats, including unimproved damp meadows, coastal marshes, flushes, downland, and Breck grassland. It requires a medium to tall sward containing its larval food plants: common sorrel and sheep sorrel, and its preferred nectar plants: ragged robin, meadow thistle, marsh thistle, viper's bugloss and devil's bit scabious, the preferred nectar source varying with habitat. It is typically found in small, discrete colonies and can occur in large numbers.

It is a day flying moth, and in warm years flies from mid-May through to July, with a few individuals occasionally recorded flying in early August. It produces a single generation a year, and has a relatively poor dispersal ability (Blaschke, Conradi & Lang 2002; Van der Meulen & Groenendijk 2005), with adults usually remaining close to the existing colony.

Eggs are laid in small batches. It overwinters as a partly grown larva, low down in the sward. At first it mines the leaves of the host plant, then feeds exposed on the lower leaves. It pupates in a cocoon spun near the ground and concealed by vegetation.

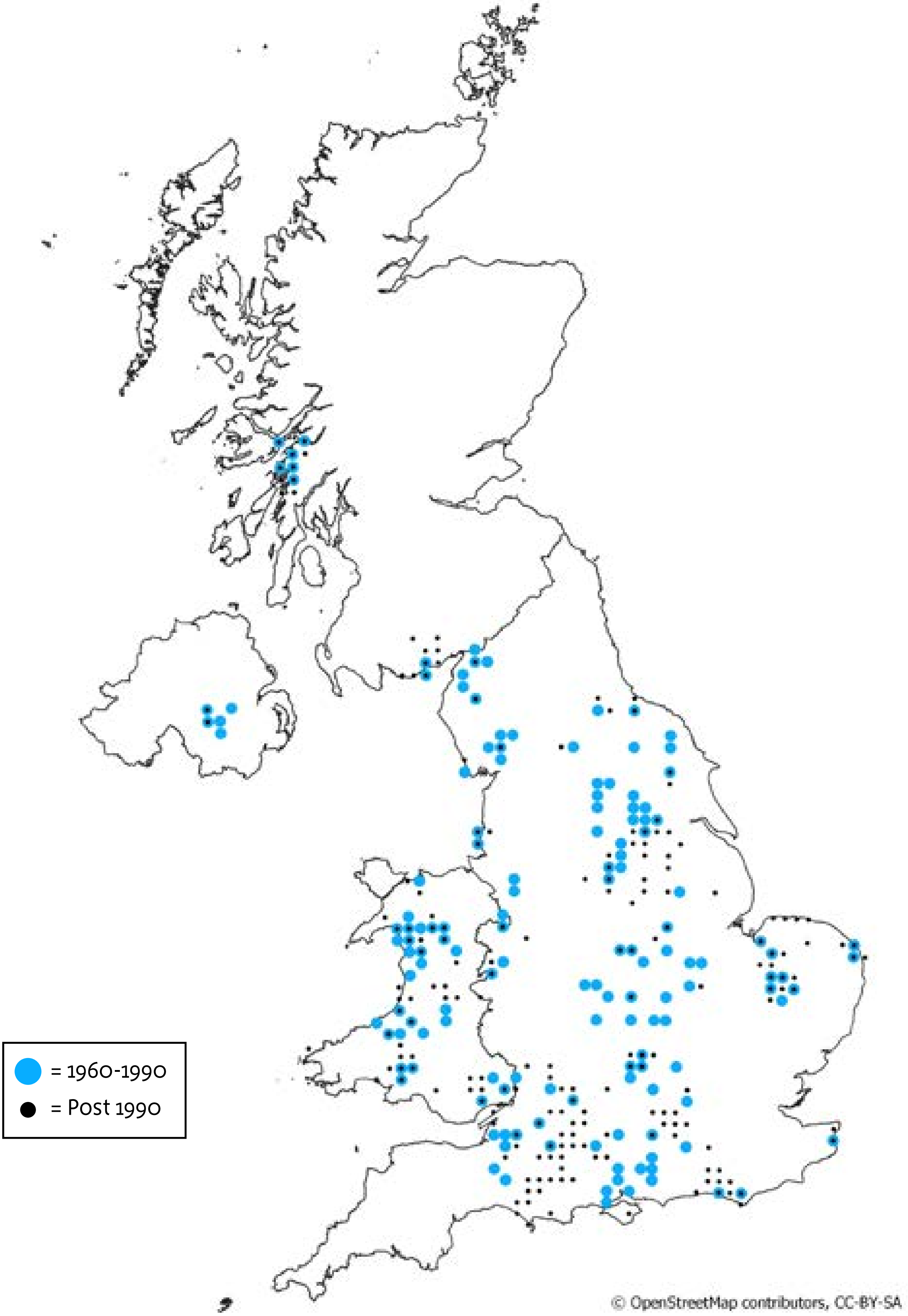
The forester has disappeared from almost half of its recorded localities since the 1940s, and losses have been particularly severe in the north (Heath & Emmett 1985). The species is found more frequently at sites within landscapes with high levels of unimproved grassland (Franzén 2002) and other semi-natural habitats. Historically the forester has been under recorded (N. Bourn pers. com.) and the apparent shift in its distribution in many regions reflects this, rather than climate driven change.

It has been declining in England and also across much of its European range (Pettersson, Nilsson & Franzén 2013), primarily due to agricultural intensification of grassland sites. Land abandonment or under-management, leading to encroachment by scrub and trees, has also been implicated in its loss from sites (Öckinger *et al* 2006; Fox 2013). In Europe the moth is still regularly found in protected areas of wetlands.

Management through light grazing to control scrub encroachment is recommended, but overgrazing is detrimental.

Butterfly Conservation's National Moth Recording Scheme presence records for Forester over 2 timeslices, 1960-1990 and post 1990, are shown on the map below (10km grid scale).

Presence of Forester records, 10km².
Source: Butterfly Conservation: Butterflies for the New Millennium.



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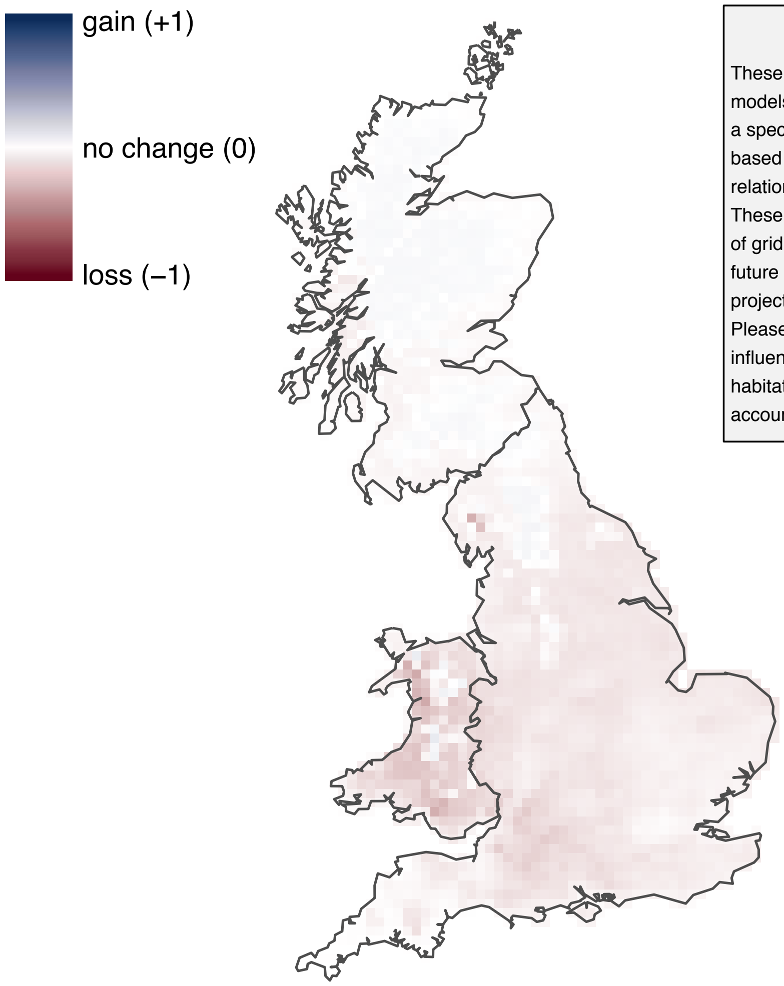
Confidence in climate change impacts[24]

Distribution change: **LOW CONFIDENCE** Mechanism: **LOW CONFIDENCE**

Climate envelope modelling suggests that the climate in England is likely to become less suitable for the forester, meaning that climate change is likely to play an increasing role in the species decline. The species itself is thermophillic, preferring warm microhabitats, but its preferred habitat appears to be wet or damp meadows or flushes, which are likely to be adversely impacted by changes in rainfall patterns, especially summer drying. Ensuring hydrological conditions are maintained in these wetter locations is likely to be a key adaptation response. In drier downland and Breck grassland habitats, wetter conditions may mean habitats become grassier. This is potentially detrimental for the forester and more ground disturbance may help to maintain suitability.

24 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Projected change in potential distribution of forester in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015).

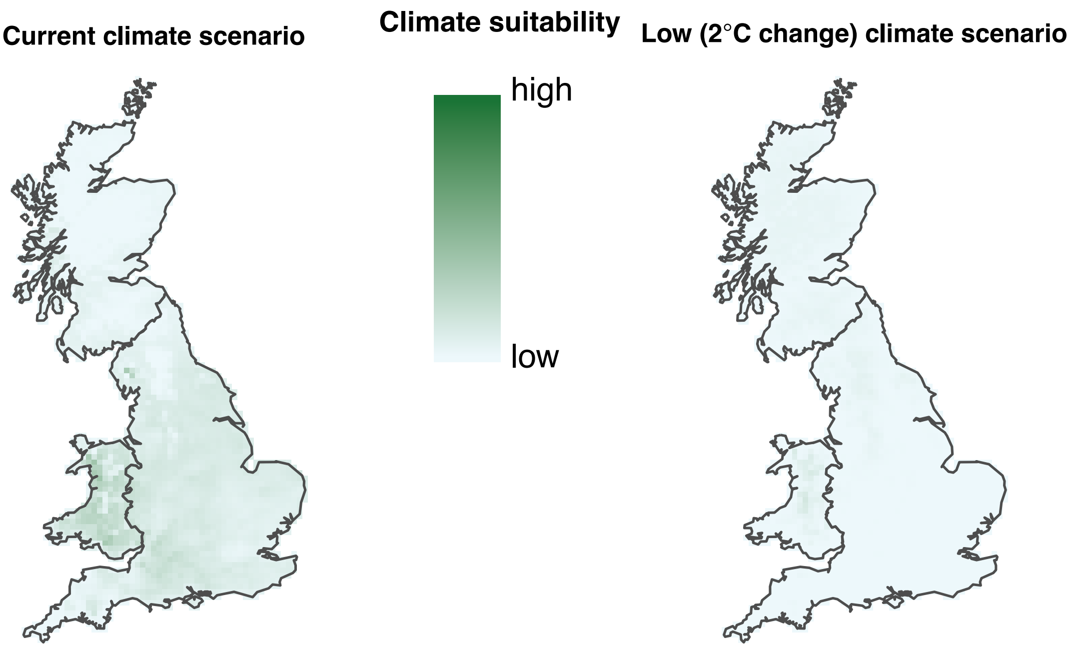


Climate suitability

These maps are created using statistical models which describe the probability that a species will be found in a 10 km grid square, based on its current distribution and its relationship to a number of climatic variables. These can be used to model the suitability of grid squares for a species under possible future climates when climate change projections are taken into account. Please note that other variables that influence species distributions, such as habitat and land–use change, are not accounted for in the modelling process.

Confidence of change

An assessment of the available data and other factors, as part of Natural England's Research Report NECR175, suggests that our confidence in this projection is very high. N.B. many confidence assessments are rated as low because there is a lack of published information on the likely influence of climate on the species concerned.



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Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

The conservation or restoration of existing sites is the starting point for adaptation. Evidence suggests that buffering of existing sites through the restoration or creation of species rich grassland (Bergman *et al* 2008) and other semi natural habitats (Slancarova *et al* 2014) will also help build the resilience of existing populations.

- Site management to ensure the maintenance of a medium-tall sward with abundant sorrel and nectar plants. Scrub encroachment can be prevented through light grazing or clearance. Over-grazing should be avoided.
- Where possible, increasing the area of suitable habitat around existing sites by restoring or creating species rich grassland, and managing scrub on existing grassland sites, can help to increase populations.
- Identify areas within existing sites and the surrounding landscape that are likely to remain relatively unaffected by climate change, for example areas with a good water supply that are likely to remain damp, and ensure that these are under optimal management.
- Take measures to ensure that sites are not adversely affected by changes in hydrology, particularly reduced summer water levels and drying.
- When targeting habitat creation, identify sites that will increase the topographic variation covered by semi-natural habitats.
- Monitor known populations to determine the extent of any change. Measures should also be put in place to monitor the impact of adaptation actions.
- Undertake research to understand the species' habitat requirements at the landscape scale, to improve the targeting of habitat restoration and creation.
- If it is suspected that climate change is responsible for losses, undertake research to identify the mechanisms driving these losses.

Relevant Countryside Stewardship options

GS6 ***Maintenance of Species Rich Grassland***

GS7 ***Restoration towards Species Rich Grassland***

GS8 ***Creation of Species Rich Grassland***

GS13 ***Management of grassland for target features***

SP9 ***Threatened species supplement***

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Golden plover
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Golden plover *Pluvialis apricaria* (Linnaeus)

Breeding populations

Climate Change Sensitivity:	HIGH	Ability to Manage:	HIGH
Non climatic threats:	HIGH	Vulnerability:	MEDIUM

Wintering populations

Climate Change Sensitivity:	POTENTIAL BENEFIT	Ability to Manage:	LOW
Non climatic threats:	LOW	Vulnerability:	LOW

Summary

Breeding golden plovers are found in upland habitats, especially heather or grass moorland and blanket bog. In winter, they vacate their breeding grounds and move to lower agricultural land or the coast, where they are joined by large numbers of migrants from Scandinavia. Breeding populations are vulnerable to warmer, drier summers due to the impacts on their favoured prey, craneflies, and adaptation aims to reduce drying by actions such as blocking drainage on bogs and wet moorland. Population resilience can also be enhanced by reducing other environmental pressures such as predation and disturbance. Warming temperatures may increase vegetation growth, reducing the availability of preferred short vegetation for breeding, requiring management such as grazing and cutting. Wintering populations are likely to be favoured by climate change, as warmer winters reduce the likelihood of frozen ground, ensuring that soil invertebrates are readily available. However, in cold winters, when golden plovers are often pushed to the coast, loss of coastal habitats as a result of sea level rise could have an impact.

Description

During the breeding season, the male golden plover has a striking appearance, with golden speckled plumage above and a solid black front, edged with white. Females are less distinctly marked, and in winter both sexes are more uniformly covered in golden-brown speckling.

Ecology and distribution

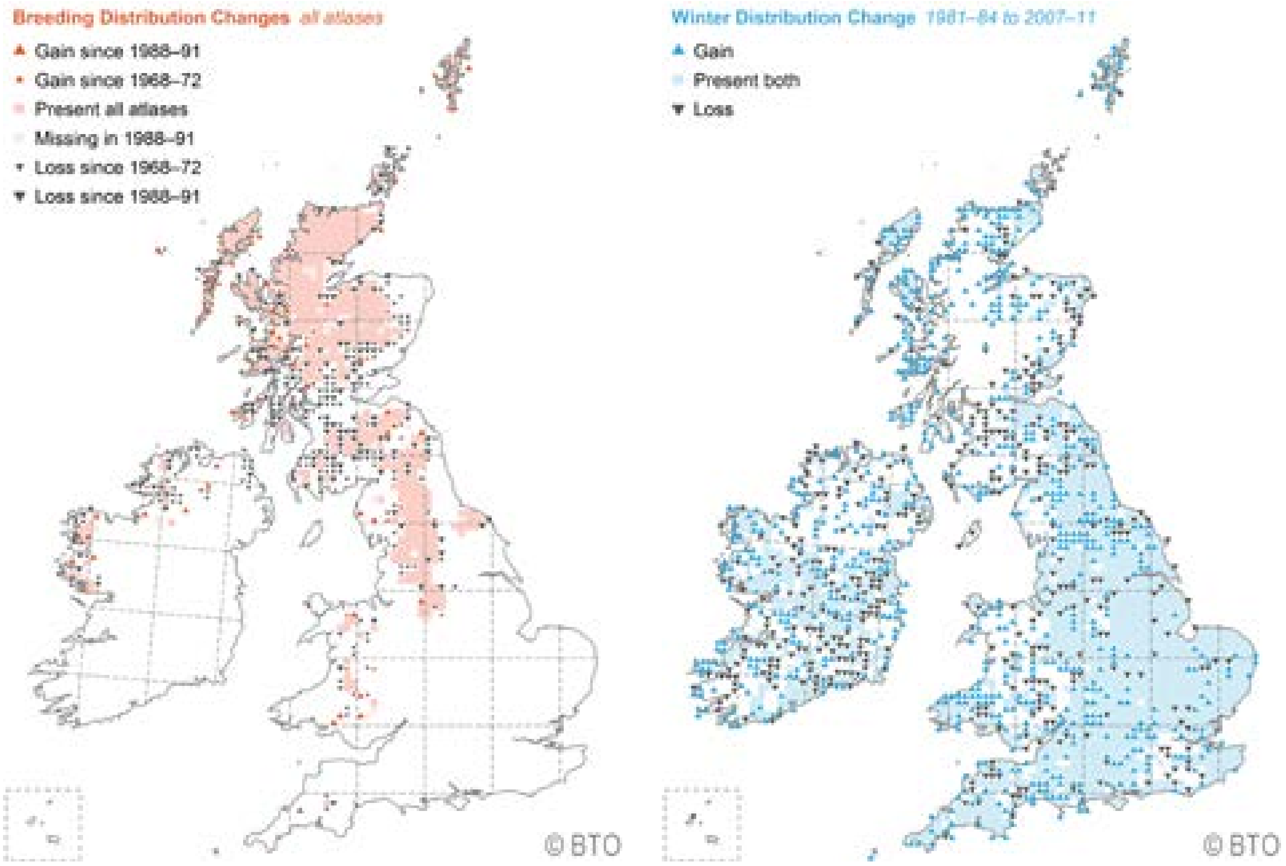
Breeding golden plovers are birds of flat or gently sloping heather or grass moorland or blanket bog, and avoid tall or dense moorland vegetation, and woodland and its vicinity. Population densities tend to be related to the productivity of the land, being higher on base-rich soils, near pastures or regularly burned moorland, and lower on acid soils. Moderate densities of breeding birds are 2-4 pairs per km^2, but can be higher in productive areas. The British and Irish breeding populations are considered distinct and are relatively isolated from the populations of Scandinavian birds that visit in winter.

In England, breeding golden plovers are found mainly in the Pennines and North York Moors. Small numbers nest in Cumbria, but the populations in south-west England (Dartmoor/Exmoor) are effectively extinct. Population declines have been attributed to afforestation, increases in generalist predators (such as crows and foxes), changes to hill farming and, in some areas, disturbance from recreational walking (Crick 1992; Finney *et al* 2005; Fletcher *et al* 2010). Drying of peatland soils, as a result of artificial drainage and summer warming, has also been detrimental (Pearce-Higgins *et al* 2010). These declines match those that have occurred throughout NW Europe, where declines in range at the southern limits of its distribution have been related to loss of heathland to agricultural improvement and afforestation (Crick 1997).

Golden plovers usually leave their upland breeding areas in winter, but flocks return to low-lying pastures near their breeding grounds in mid-February. Territory establishment takes place on adjacent, higher altitude moorland during March, and the majority of eggs are laid in April and May. Pairs do not use their territories for feeding until their eggs hatch, preferring to feed on flushes, spring complexes and 'improved' pastures which may be distant from their breeding site. After they fledge at 5-6 weeks old, the young birds join flocks feeding on adjacent pastureland. Territorial defence of the nesting area ceases once the chicks hatch, although the birds are territorial around the mobile chicks, and birds that have not managed to breed may take over vacated nesting areas for their own breeding attempts.

The populations of Iceland, Scandinavia and Russia are wholly migratory, and many of these winter in England. Wintering flocks use inland fields of mown grass, closely cropped pasture, stubbles and fallow, and often feed in mixed flocks with lapwings *Vanellus vanellus*. They prefer to feed on permanent pastures because of the larger densities of soil invertebrates, but will roost in the centre of large bare fields that have been ploughed. Wintering populations have generally increased over the past 40 years.

Historic changes in the distribution of UK breeding and winter populations of Golden Plover (reproduced with permission of the BTO, from Balmer *et al* 2013)



Confidence in climate change impacts[25]

Breeding populations

Distribution change: **HIGH CONFIDENCE** Mechanism: **HIGH CONFIDENCE**

Wintering populations

Distribution change: **HIGH CONFIDENCE** Mechanism: **MEDIUM CONFIDENCE**

Breeding golden plovers are projected to be at high risk from climate change. Analyses of suitable climate space suggest that there will be substantial losses of suitable space under both 2° C and 4° C climate change scenarios, leaving only small areas that will be potentially suitable sites in the uplands of Scotland and northern England. Detailed research has shown that the emergence of adult craneflies provides an important flush of food for young birds (Pearce-Higgins & Yalden 2004) and that high summer temperatures may kill cranefly larvae by drying out the surface of peatland soils (Pearce-Higgins *et al* 2010). This affects the number of larvae hatching out the next spring – with numbers of adult cranefly emerging down by as much as 95% (Pearce-Higgins *et al* 2010). Thus, the abundance of golden plovers is affected by dryness of the summer (especially August temperatures) two years previously: a hot summer will result in reduced cranefly emergence in the following year, and hence low golden plover productivity, resulting in few recruits and a population decline in the second year.

25 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Another factor that has the potential to affect the survival of young golden plovers is mismatch between the emergence of craneflies and the hatching of chicks (Pearce-Higgins *et al* 2005. With climate warming, both are occurring earlier, but cranefly emergence is advancing more slowly than plover hatching, so that the plovers are increasingly missing the peak emergence of the craneflies, leading to reduced survival rates. However, this factor appears to be less important than the overall reductions in cranefly numbers due to the drying out of peat (Pearce-Higgins *et al* 2010).

Given the strong association between golden plovers and short vegetation (Pearce-Higgins & Yalden 2004), another plausible mechanism could be warming leading to increases in vegetation growth rates. This might reduce the areas of structurally suitable habitat for the species.

In contrast to breeding populations of golden plover, the important wintering populations that live on the wet grasslands and arable fields of lowland Britain have increased substantially in recent years. An analysis of the abundance of wintering populations suggests that they will be favoured by climate change, with substantial increases in the area of suitable climate (Pearce-Higgins *et al* 2015). This is likely to occur through the reduced probabilities of freezing weather, which would negatively affect the availability of the soil invertebrates in wet grassland upon which they feed. In addition, there is evidence of shifts away from inland sites to eastern estuaries, which may be attributable to increases in temperature and declines in invertebrate food availability on agricultural land. One potentially negative impact of climate change on the coast would be the impact of rising sea levels on the availability of foraging habitat and roosting or loafing areas due to more frequent flooding of coastal grazing marsh. This might be exacerbated by increasing levels of disturbance due to recreational use of coastal sites.

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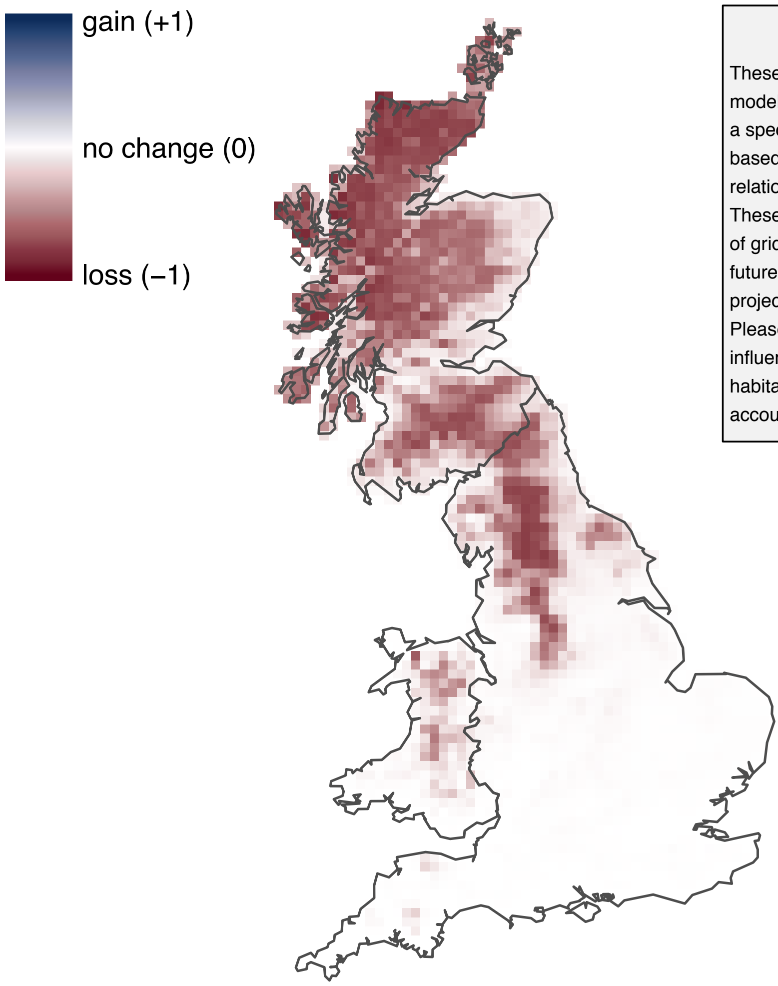
Projected change in potential distribution of golden plover (breeding population) in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015).

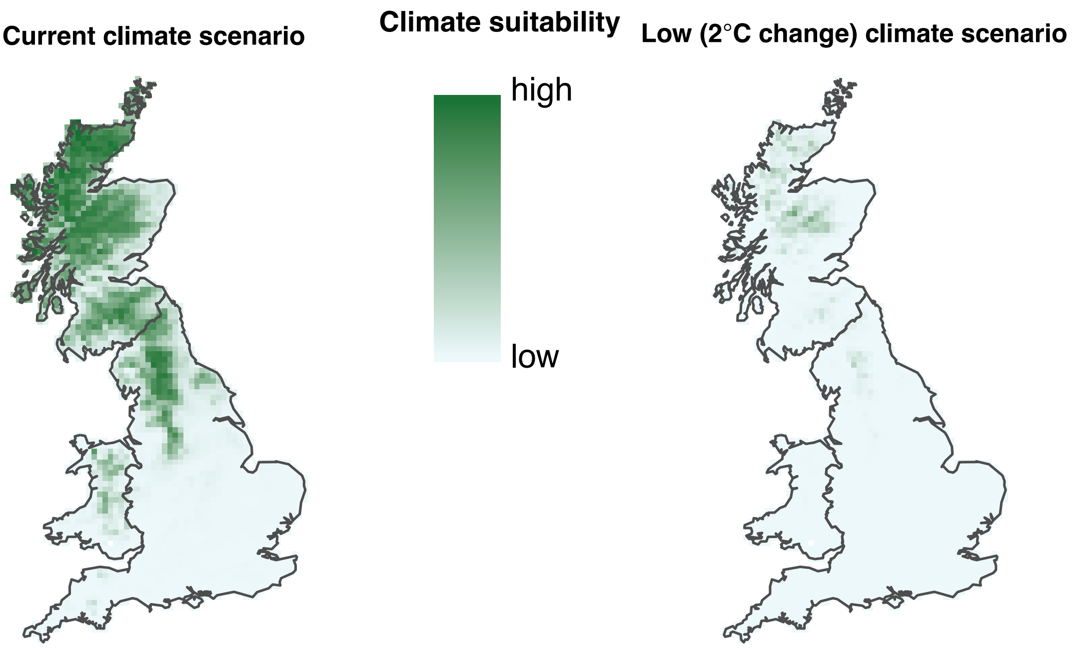


Climate suitability

These maps are created using statistical models which describe the probability that a species will be found in a 10 km grid square, based on its current distribution and its relationship to a number of climatic variables. These can be used to model the suitability of grid squares for a species under possible future climates when climate change projections are taken into account. Please note that other variables that influence species distributions, such as habitat and land–use change, are not accounted for in the modelling process.

Confidence of change

This species was not included as part of Natural England's Research Report NECR175 assessing the risks & opportunities for species in England as a result of climate change, so no assessment of confidence has been made for this species



Created by: University of York | Created for: Natural England | Created on: August 17 2016

Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

If current warming trends continue, many golden plover populations, especially those in the south of the bird's range where temperature rises will be highest, are likely to decline. However, because this species has been so well studied, our understanding of the processes linking climate, food resources, breeding success and population sizes, gives us the opportunity to respond. Adaptation management can be separated into two forms: counteracting and compensatory (Green & Pearce-Higgins 2010). Counteracting management reduces the severity of the negative climate change impact, while compensatory management does not address the mechanism by which climate change impacts upon a species, but seeks to increase productivity or survival rates through other mechanisms. For the breeding golden plover populations, there are options available to apply both counteracting and compensatory management practices.

The key mechanism by which golden plovers are affected by climate change is through the drying out of their wet bog and peaty upland heather moor habitats in the late summer, resulting in reductions of their cranefly prey in the following year. Management to increase cranefly populations requires blocking drainage ditches to raise and maintain water levels and re-vegetating bare peat, thereby increasing the resilience of the system to future warming. (Carroll *et al* 2011, 2015).

Modelling work has shown that compensatory action might also provide important population resilience, by tackling other factors that reduce golden plover populations. Breeding wader populations can be limited or decline as a result of generalist predators preying on nests and chicks. For example, one study showed that 18% of golden plover pairs successfully fledged young in areas with no predator control, compared with 75% in areas with predator control (Fletcher *et al* 2010). Legal control of generalist predators, especially foxes, has also been shown to benefit other wader species. The population models suggest that reducing the abundance of predators through control and other forms of management, and thereby increasing nesting success, may increase the resistance of a population to climate change. Thus, population persistence increases despite declines in productivity due to the warming effect on cranefly abundance.

There is a range of other management options that might be useful for golden plovers.

- To counter the possible impact of increased vegetation growth rates with warming, a potential adaptive response would be to manage the vegetation through suitable grazing or cutting regimes to create the short vegetation that the species prefers.
- Declines in numbers of upland breeding golden plovers have been associated with local exposure to forest edges (Amar *et al* 2011). Hence, key measures to benefit this species are to remove conifer plantations, and avoid new planting of both conifer and broadleaved woodland in areas close to golden plover breeding grounds.
- Populations of golden plovers which breed on upland heath feed on surrounding agricultural land. Thus, the provision of suitable conditions for foraging on this

agricultural land that encourage high densities of earthworms and craneflies, should also increase the resistance of these populations to climate change. Traditionally managed unimproved pasture is particularly valuable foraging habitat for these species, so it will be important to ensure these pastures are maintained.

- Recreational disturbance can be of localised importance for upland bird species such as the golden plover. In cases where disturbance may be limiting breeding success or distribution, measures to manage people by diverting them away from the most sensitive areas may help increase the resilience of those populations to climate change.

Wintering populations are likely to benefit from climate change through reductions in freezing conditions that would limit access to soil or inter-tidal invertebrates. Thus, adaptation actions should aim to ensure that there are suitable foraging and roosting areas in parts of the country where they currently occur and might occur in the future. It will be important to ensure that the foraging areas are not subject to excessive disturbance and are maintained in a damp condition.

Relevant Countryside Stewardship options

Several Countryside Stewardship options for lowland and upland marginal farmland and moorland are likely to offer benefits for breeding and over-wintering golden plovers. The most relevant options are listed below:

Breeding areas

GS5 Permanent grassland with very low inputs in Severely Disadvantaged Areas (SDAs)

GS9 Management of wet grassland for breeding waders

GS13 Management of grassland for target features

GS14 Creation of grassland for target features

SP2 Raised water level supplement

SP9 Threatened species supplement

UP1 Enclosed rough grazing

UP2 Management of rough grazing for birds

UP3 Management of moorland

UP4 Management of moorland vegetation supplement

UP5 Moorland re-wetting supplement

WT10 Management of lowland raised bog

Wintering areas

AB2 Basic overwinter stubble

AB6 Enhanced overwinter stubble

CT3 Management of coastal saltmarsh

GS2 Permanent grassland with very low inputs (outside SDAs)

GS10 Management of wet grassland for wintering waders and wildfowl

GS12 Creation of wet grassland for wintering waders and wildfowl

OP1 Overwintered stubble

Case Study

Blanket bog restoration at Dove Stone RSPB reserve

Since 2010, a partnership between RSPB and United Utilities has been restoring 2,500 ha of degraded peatland at the RSPB Dove Stone reserve in the Peak District National Park. Working with tenant farmers, the project involves re-vegetating bare peat, blocking eroded gullies to hold water back and slow flows, and planting over 300,000 individual handfuls of peat-forming sphagnum moss. The work is ongoing, but there have been increases in breeding dunlins, golden plovers, curlews and red grouse, and these populations will be resilient to climate change impacts in the future through the provision of more drought resistant habitats.

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Great crested newt
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Great crested newt *Triturus cristatus*

Climate Change Sensitivity:	MEDIUM	Ability to Manage:	HIGH
Non climatic threats:	HIGH	Vulnerability:	MEDIUM

Summary

Great crested newts are native to northern Europe, including England where significant populations can be found. Lowland arable farmland is a key habitat for the species, which is facing declines across its range. Increasingly mild, wet winters and hot dry summers are a threat to the species, affecting both survival and breeding success. The key adaptation responses are to improve habitat quality and extend the network of aquatic habitats across the landscape. Improving connectivity between breeding ponds can help improve dispersal opportunities and the resilience of the newt population.

Description

Great crested newts are the largest of three native newt species found in England and occupy a wide variety of terrestrial habitats, including deciduous woodland, farmland and various types of semi-natural grassland. Great crested newts forage in a range of water bodies and are adept at exploiting new breeding opportunities when they arise. Facing declines across their range, the species is afforded strict protection under Annexes II and IV of the *Habitats Directive, the Conservation of Habitats & Species Regulations 2017, and the Wildlife & Countryside Act 1981*.

Ecology and distribution

The great crested newt requires both aquatic habitats, for breeding and feeding (and also occasionally over-wintering), and terrestrial habitats, for feeding, shelter, hibernation and dispersal. Newts start emerging from hibernation when conditions are suitable, usually on damp, warm nights with air temperatures reaching at least 5°C. Adults migrate to breeding ponds from late winter to spring After spending anything from a few days to several months in these breeding ponds, they migrate back to terrestrial habitats during late spring to late summer. Migration and foraging on land occurs at night, particularly on warmer, damp nights. Great crested newts do not have a selective diet and will consume a variety of invertebrates and amphibian larvae.

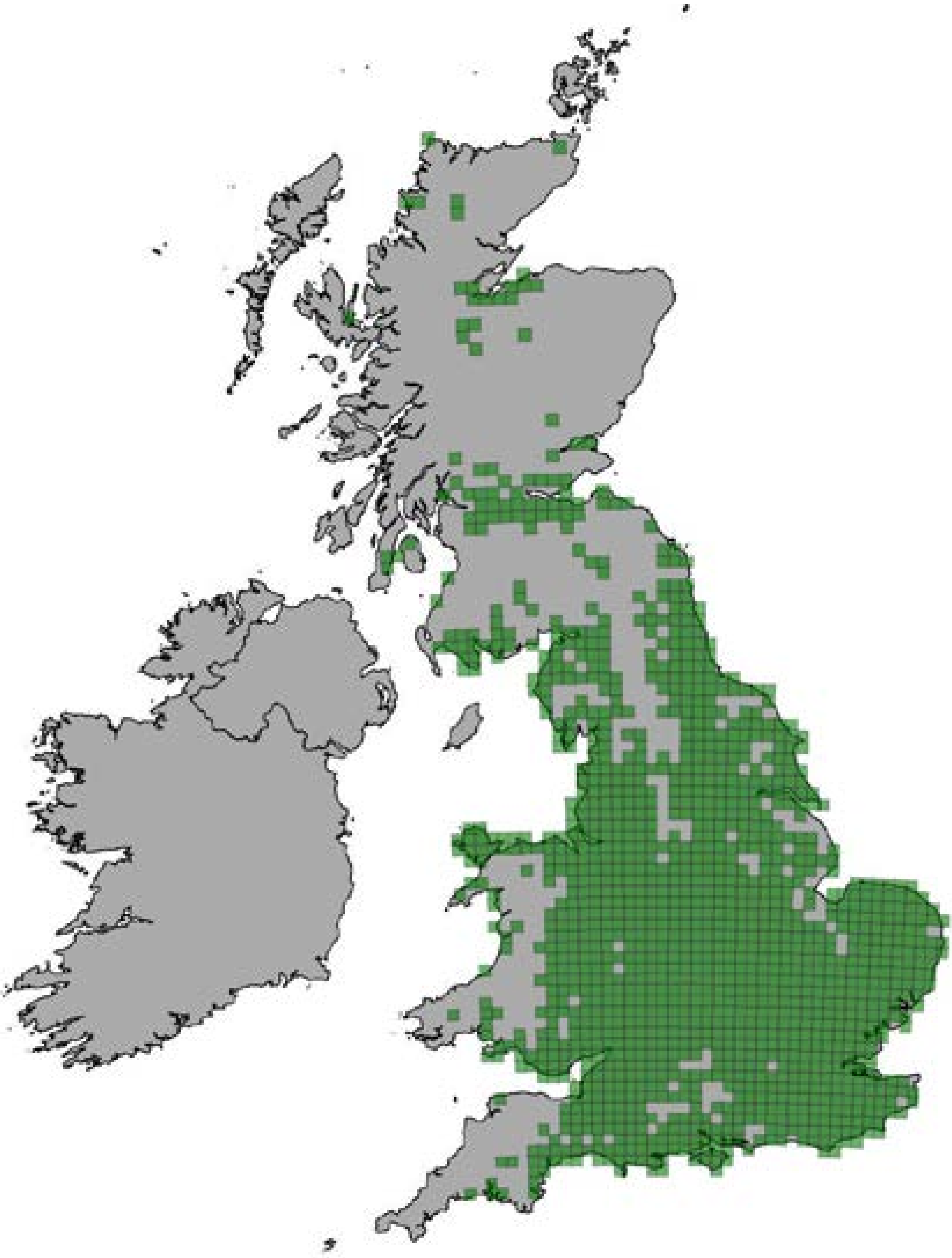
Female newts deposit eggs singly onto leaves. Larval development takes about 16 weeks, after which the juvenile newt will emerge onto land to forage and disperse to other ponds. They are sexually mature after about two to four years and can live for more than ten years in the wild.

During the species' active period, good ground cover such as grassland tussocks, dead wood and woodland debris are essential for shelter. For hibernation, refuges such as burrows, old root systems and similar habitat features are important. Breeding ponds are usually about $50m^2$ to $250m^2$, with small garden ponds and lakes typically unsuitable. Good quality ponds have aquatic vegetation for egg laying and cover, some open areas for courtship displays, a lack of shade on their southern edges, and are ideally neutral or slightly alkaline. Great crested newts are susceptible to predation from fish, so ponds that dry out occasionally will help to reduce predator numbers, but may affect recruitment for that year if drying occurs before August.

Great crested newts demonstrate meta-population dynamics, with sub-populations occupying a number of ponds within a landscape, connected by suitable terrestrial habitat. The maximum dispersal distance of great crested newts is roughly 1km, but the average is approximately 250m (Griffiths 2004). Connectivity between occupied ponds is vital to maintaining sustainable meta-populations.

Great crested newts are facing declines across most of their range (Antzen *et al* 2009). In England, historical information about great crested newt distribution is very patchy prior to the 1980s, but it is thought that the species declined by 50% between 1965 and 1975 and then by 2% every five years (Nicholson & Oldham 1986). In some areas, the annual decline of the species is as much as 5% (JNCC 2010). The key factors contributing to declines include loss of ponds, terrestrial habitat fragmentation and other habitat loss (Edgar & Bird 2006). In addition, the quality of remaining ponds has declined substantially in many areas (e.g. through succession, pollution and fish introductions), which has exacerbated the declines (e.g. Williams *et al* 2010). Accurate estimates of newt populations are difficult to calculate, but it is thought that there are approximately 54,000 occupied ponds, which equates to almost 20% of all ponds in England (Wilkinson *et al* 2011).

Presence of great crested newt records, 10km², NBN Atlas



The National Biodiversity Network presence records for great crested newt are shown on the map above (10km grid scale). (See **terms and conditions**, see Appendix 1 for the list of datasets included)

Confidence in climate change impacts[26]

Distribution change: **LOW CONFIDENCE** Mechanism: **MEDIUM CONFIDENCE**

At the northern end of its UK range, earlier spring conditions may have a positive influence, with earlier emergence from hibernation extending the active period and therefore potentially increasing recruitment and juvenile dispersal opportunities (Dervo *et al* 2016). However, elsewhere, milder winters may reduce the viability of newt populations, with mild and wet winters associated with lower survival rates as a result of waterlogged soils or depletion of individual energy reserves during the hibernation period (Griffiths *et al* 2010). Hot dry summers have been shown to have an adverse impact on populations (Weinbach *et al* 2018) There is limited evidence of a climate driven delay in spring arrival of newts to ponds (Thompson 2017) thereby increasing the potential threat of egg desiccation due to drying. Warmer and drier summers could reduce the availability of aquatic habitat and prey, thereby impacting recruitment levels if ponds dry out before the larvae develop into juvenile newts. The increased prevalence of summer drought could adversely impact populations in the south and east. Occasional drying of ponds helps eliminate predators, however earlier or prolonged drying incidents can lead to direct mortality of eggs and juveniles or indirect losses through the loss of aquatic and marginal vegetation. Disease risk may also change with temperature shifts, possibly increasing the prevalence of disease such as the chytrid fungus *Batrachochytrium dendrobatidis* (Pounds *et al* 2006). Although relatively resilient to moderate water quality, extreme rainfall events leading to an increased incidence of pollution could adversely impact local population viability.

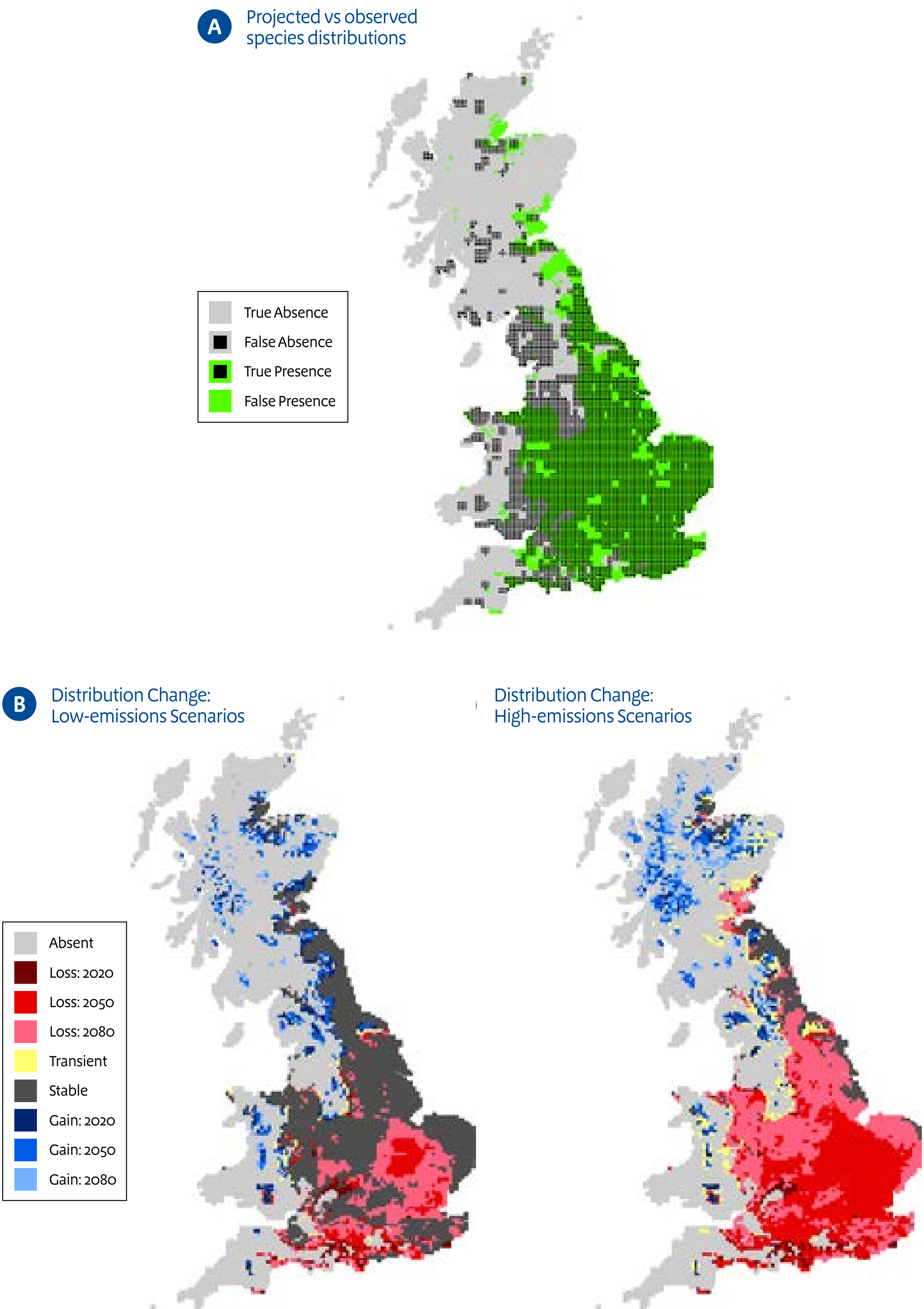
Rixton Clay Pits Local Nature Reserve. © Natural England/Ruth Critchley

To date changes in the distribution of great crested newt have been driven by non-climatic causes, however climate change modelling indicates that by 2050, under a low emissions (2 °C increase) scenario, large areas of southern and central England may become unsuitable (Dunford & Berry 2012). Populations in areas including the coastal east, north-east and West Midlands are projected to remain stable, and small gains may be made in central and northern England and in Scotland (Fig. 1).

Please read this case study alongside the relevant habitat sheets.

26 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Figure 1: Projected present distribution and changes in distribution of great crested newts under two greenhouse gas emissions scenarios (from Dunford & Berry 2012).



Adaptation options

To promote resilience of great crested newt populations in the face of climate change, actions should focus on improving connectivity and habitat quality, to improve survival and recruitment at a landscape scale. Specific intervention to address the threat of early and frequently repeated drying should be considered in areas prone to drought. Potential actions include:

- Improving connectivity between ponds and known newt sites by creating or improving connecting habitat or creating new stepping-stone ponds (within about 250m of known newt ponds is ideal). Good connective terrestrial habitats could include field margins, woodland, hedgerows, scrub and grassland.
- Improving pond quality and the number of ponds in the landscape by a combination of pond restoration (e.g. de-silting, clearing some shade, removing fish), pond creation, and reducing run-off from surrounding land to improve water quality.
- Although the periodic desiccation of ponds can be beneficial in terms of eliminating predators the management of the hydrology and shading of ponds should aim to reduce the risk of earlier drying, and ponds remaining dry for protracted periods of time.
- In locations where periodic desiccation occurs and is likely to increase, the restoration or creation of new ponds in relatively close proximity (within about 250m) should aim to produce a localised cluster to enable re-colonisation of desiccated sites.
- Maintaining good biosecurity on and between sites to minimise disease risk and monitoring to detect changes in populations status and distribution. Species sightings should be reported to a local record centre or amphibian and reptile group, and dead or sick animals to the **Garden Wildlife Health** project.

Relevant Countryside Stewardship options

The most relevant options are those that seek to create a good mosaic of different habitats (grassland, woodland, scrub), with a network of suitable ponds. Options that improve the water quality of aquatic habitats will also be beneficial.

The Amphibian and Reptile Conservation (ARC) Trust has published a **leaflet** which provides guidance to land managers on options to support great crested newts. While this relates to the previous Environmental Stewardship Scheme and the options and codes may have changed, this is still a useful resource for identifying relevant options. Below are a selection of options that should benefit great crested newts:

WN5, WN6	***Pond management (and creation)***
WT1, WT2	***Buffering in-field ponds and ditches***
WT3, WT4, WT5	***Management of ditches and ponds of high environmental value***

Case Study

One case study in southern Estonia demonstrates the benefits of pond restoration and creation at a larger scale for amphibians, including the great crested newt (Rannap, Lõhmus & Briggs 2009). Ponds were restored or created in pond clusters, which increased the density of ponds at a local level as well as at the landscape scale. Pond diversity was increased (variation in pond depths, water levels and pond edges) and wetlands connected to suitable terrestrial habitat were restored. Over three years, 22 ponds were restored and 208 new ponds created, within protected areas covering approximately 700 ha. By restoring 5% of existing ponds and increasing the number of ponds by 50%, the number of ponds occupied by great crested newts increased by 230% over three years.

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Keeled skimmer
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Keeled skimmer *Orthetrum coerulescens* F.

Climate Change Sensitivity:	HIGH	Ability to Manage:	MEDIUM
Non climatic threats:	MEDIUM	Vulnerability:	MEDIUM

Summary

The impact of climate change on the keeled skimmer is likely to result from changes in rainfall and a lowering of water tables, leading to the loss and degradation of its habitat in the south and east of England. The keeled skimmer responds well to management interventions that maintain water levels and manage vegetation, especially where this sustains shallow, largely unshaded areas of open water. Where climate change will adversely affect water levels, the restoration of natural hydrology to secure water levels, or intervention to secure greater control of water levels, including the creation or restoration of ponds, are likely to be the most effective forms of adaptation.

Description

The keeled skimmer is the smallest of the four blue skimmers and chasers. Its wings are characteristically forward facing when perched. Males have a pastel blue abdomen, without a dark tip. Juveniles lack the blue colouration of the adults. Females are yellow and have tinted yellow wings. The lack of a black tip to the abdomen and the coloured wing segment (pterostigma) can be used to differentiate between similar species. It has a rapid and unpredictable flight pattern, usually near the edge of the water, where the pond side vegetation grows.

Ecology and distribution

In the UK, the keeled skimmer is a specialist of wet heathland and bog, especially in areas where *sphagnum* mosses thrive. It breeds in flushes, the boggy margins of streams, and in ditches and pools, in areas of moorland, heath and mire.

The keeled skimmer is territorial, and the males settle on perches to monitor activity on their patch. Eggs are laid by the female dipping the tip of the abdomen beneath the water whilst in flight. The male can be seen in close proximity guarding the female and ready to chase off other male intruders. The larvae live in the peaty detritus and silt, taking two years to develop (Merritt, Moore & Eversham 1996). Adults emerge from larvae hanging from the underside of emergent vegetation.

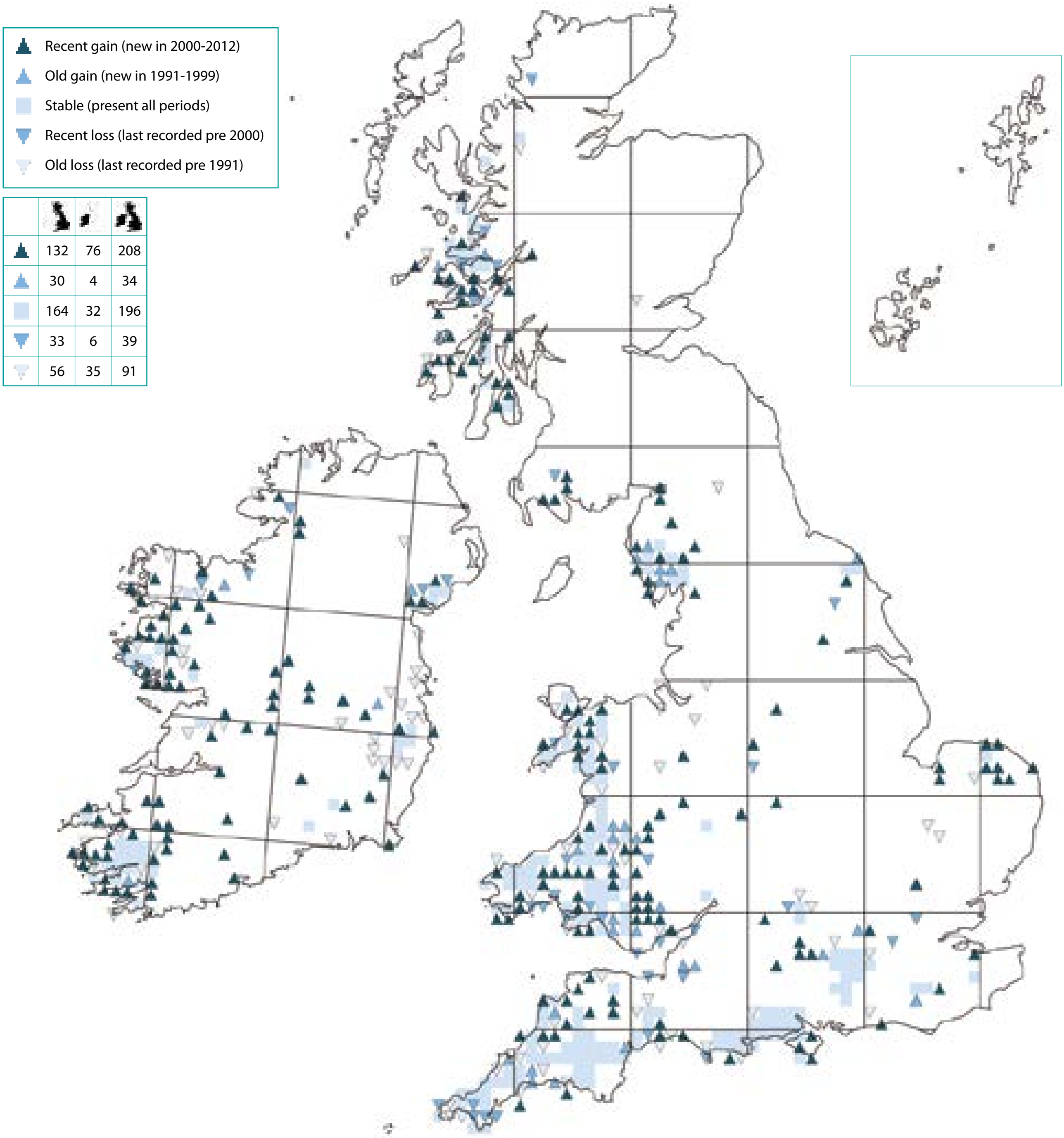
Nationally, the keeled skimmer is quite rare, but it has a patchy distribution and can be locally common. In England, it is found mainly in western areas, being abundant in Cornwall and Devon and the Surrey heaths, with the heathland areas of Dorset and the Lake District also strongholds.

Historically, declines have been related to land use change, particularly the cessation of peat digging (Moore 1986), and the loss or degradation of its habitat (Harzog & Hadrys 2017). Lowering of the water table has been implicated in its localised extinction at several sites (Merritt, Moore & Eversham 1996). Elsewhere in Europe, climate change related summer warming has been implicated in its expansion at its northern margins (Termaat, Kalkman & Bouwman 2010).

Although it is sensitive to inappropriate management such as dredging (Hadrys *et al* 2007), the keeled skimmer has been shown to be tolerant of management intervention as long as the entire meta-population is not impacted (Harzog & Hadrys 2017). In mainland Europe, the species utilises a wider range of habitats, including artificial water bodies such as canals (Harzog & Hadrys 2017), reservoirs (Fulan *et al* 2010) and ditches (Wildermuth 2008). The presence of vegetation in these artificial waterbodies appears to be important (Scher & Thièry 2005). Populations in sub-optimal areas can be maintained by relatively simple habitat maintenance (Wildermuth 2008).

The British Dragonfly Society records for keeled skimmer are shown on the map below (10km grid scale).

Presence of keeled skimmer records, 10km².



	132	76	208
	30	4	34
	164	32	196
	33	6	39
	56	35	91

Map © Natural Environment Research Council and British Dragonfly Society (2014).

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Confidence in climate change impacts[27]

Distribution change: **MEDIUM CONFIDENCE** Mechanism: **MEDIUM CONFIDENCE**

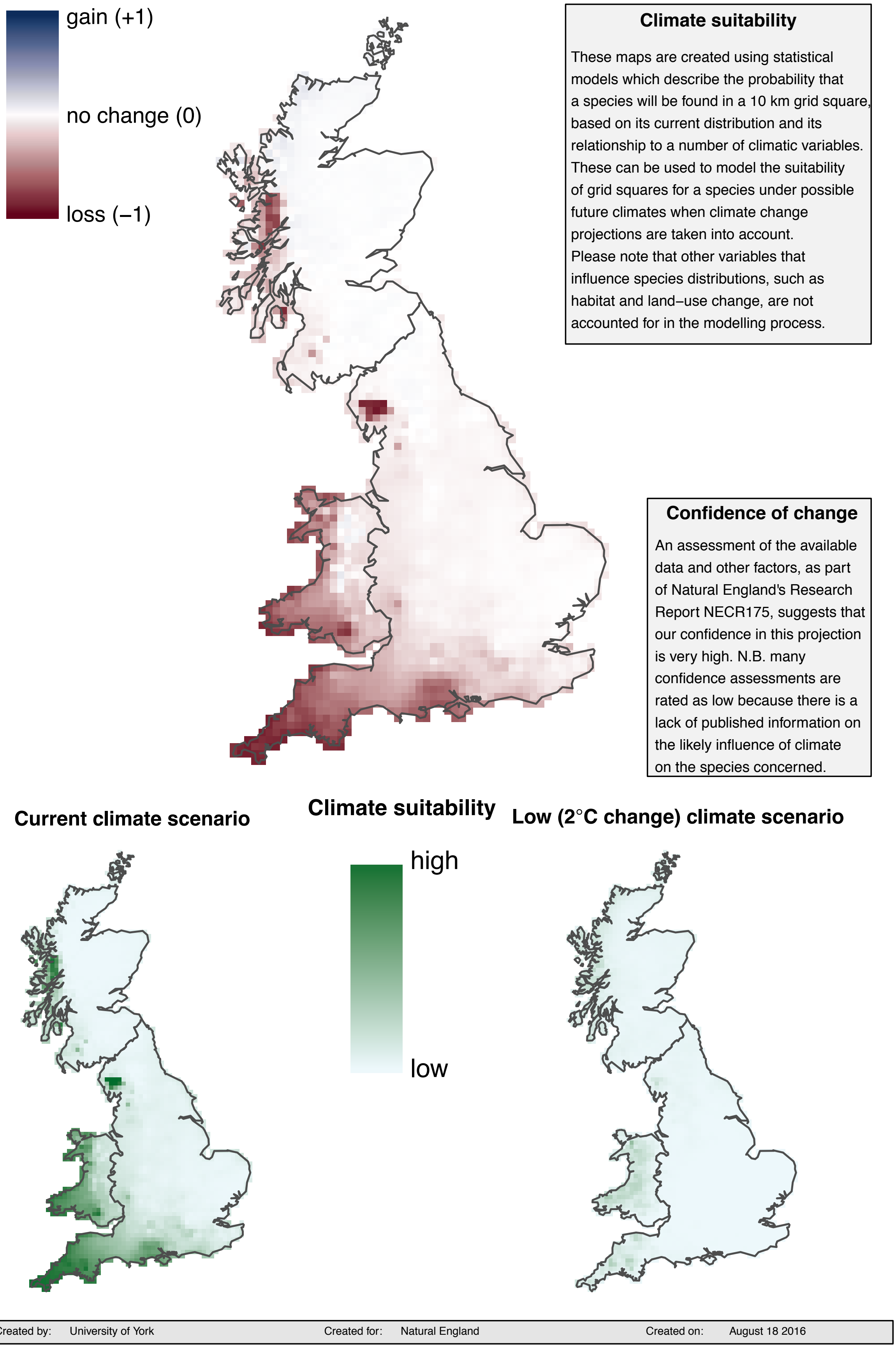
The keeled skimmer has been shown to be susceptible to drought (Harzog & Hadrys 2017) and lowering of the water table (Merritt, Moore & Eversham 1996), although it is able to persist in climatically challenging areas if water bodies are maintained artificially (Harzog & Hadrys 2017). Larval development occurs over a relatively wide temperature range compared to other species, although the growth rate is slower than for species that utilise more ephemeral habitats (Suhling, Suhling & Richter 2015). This suggests that changes to temperature will have a lesser impact, although the slow growth rate makes it more susceptible to occasional extreme events such as drought.

In the southern part of its range it has been shown to utilise shady sites (Fulan, Raimundo & Figueiredo 2008), the suggestion being that it uses shade to help it tolerate hot conditions. Such a behaviour is unlikely to be required in England. Strong wind has been shown to increase the mortality at emergence (Jakob & Suhling 1999), so the projected increase in extreme weather events may have a detrimental impact at this stage.

The direct and indirect impact of changing patterns of rainfall and abstraction on water tables, especially in the south and east of England, are likely to be the main adverse effects of climate change.

27 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Projected change in potential distribution of keeled skimmer in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015).



Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

Adaptation should focus on maintaining and restoring the hydrology of suitable open water and wetland habitats through ensuring effective on-site management and addressing off-site impacts. Maintaining water levels through artificial measures is likely to play an important role, especially in areas of the country where changes in the patterns of rainfall will lead to lower water levels or habitats drying out.

- Manage wetlands to ensure suitable open water habitat for breeding and larval development. Priority for wetland restoration and creation should be given to locations where the availability or control of water is secure.
- Ensure off-site impacts on water quantity and quality such as abstraction, drainage and diffuse pollution are identified and addressed.
- Maintain and restore the natural hydrological function of sites to support water levels during periods of drought.
- In areas most likely to be impacted by drought and falling water tables, consider maintaining water levels artificially.
- Where suitably peaty, acidic conditions exist, create new open water habitat in areas close to existing sites to build resilience within meta-populations.
- Monitor populations in sites known to be susceptible to drought, and seek to determine the mechanism for any observed changes.
- Reintroduction should be considered in locations outside its dispersal range in locations where water quantity and quality is assured.
- If the projected changes in distribution occur, areas in the wetter west will become increasingly important for this species. Conservation priorities should be altered to reflect this change.

Relevant Countryside Stewardship options

WT1 Buffering in-field ponds and ditches in improved grassland

WT2 Buffering in-field ponds and ditches in arable land

WT3 Management of ditches of high environmental value

WT4 Management of ponds of high wildlife value (100 m2 or less)

WT5 Management of ponds of high wildlife value (more than 100 m2)

WT8 Management of fen

WT9 Creation of fen

WT10 Management of lowland raised bog

UP3 Management of moorland

UP5 Moorland re-wetting supplement

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Large heath
© Marcus Rhodes

Large heath *Coenonympha tullia*

Climate Change Sensitivity:	HIGH	Ability to Manage:	MEDIUM
Non climatic threats:	HIGH	Vulnerability:	HIGH

Summary

The large heath has declined rapidly in England. Historically, this has been due to degradation of its habitat through agricultural improvement, including drainage and high intensity burning of moorland, and the loss of wetland through peat cutting, tree planting, or woodland succession. The species is at the southern limit of its range in the UK and climate change appears to be playing an increasing role in its overall decline.

Adaptation options focus on ensuring management promotes a diverse mix of mire vegetation containing bog mosses, hare's-tail cottongrass *Eriophorum vaginatum* and cross-leaved heath *Erica tetralix*. This may increasingly require greater control over the hydrology of sites to ensure optimal water levels. Assisted colonisation to establish populations in areas that are beyond the dispersal ability of the butterfly and where the climate will remain suitable can also be considered, especially on sites where the hydrology can be controlled.

Description

The large heath is a medium-sized, highly variable grey-brown butterfly (wingspan 35-40 mm) that never basks with its wings open. Males and females are similar, with the females being a slightly lighter colour. The eye spots on the underside of this species vary with latitude. Those in the north of Scotland (*ssp. scotia*) have almost no spots at all, with adults looking like a large small heath, while those in England (*ssp. davus*) have brightly coloured, distinctive spots. Intermediate forms occur in central and southern Scotland (*ssp. polydama*), although never occur south of the border, making identification of the English populations straightforward.

Ecology and distribution

The large heath is restricted to flat, boggy habitats in northern England, with a few isolated sites in the midlands and the south. Sites are usually below around 500 m in altitude, and have a base of sphagnum moss interspersed with dense tussocks of hare's-tail cottongrass. They also have abundant cross-leaved heath, the main nectar source, and other plant species characteristic of high quality mire. The optimum habitat appears to be sites with thicker peat (>0.5 m) and higher water tables (Dennis & Eales 1999).

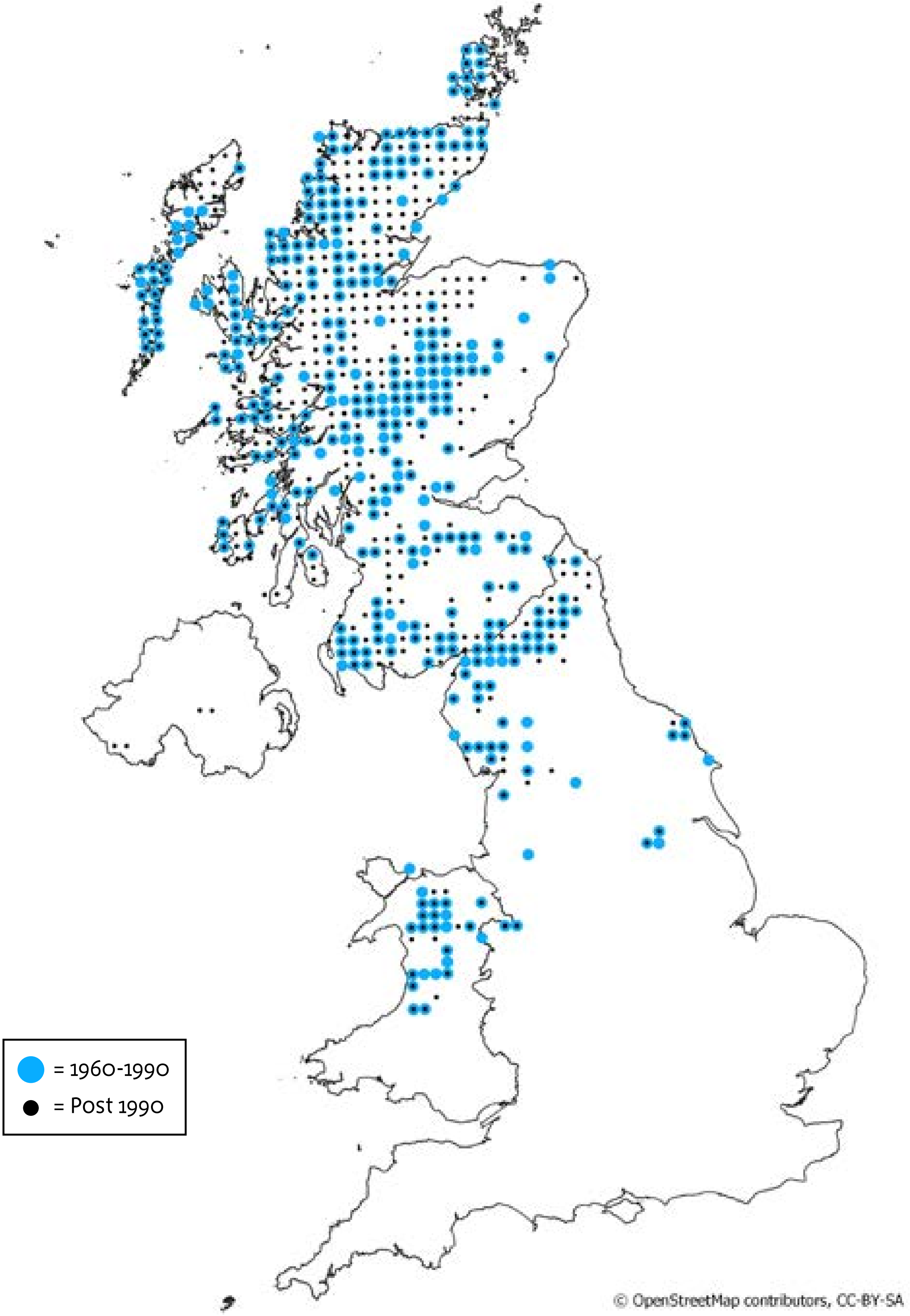
There is one generation a year, with adults flying between mid-June and early August, with a peak in mid-July. Eggs are laid singly, often on dead cotton grass. Sites dominated by tall heather are largely avoided by ovipositing females (Wainwright 2011). The larvae feed during the day from late July to late September (Joy 1991). The main host plant is hare's-tail cotton grass. Occasionally, however, they feed on jointed rush *Juncus articulates*, and in the North York Moors, common cottongrass *Eriophorum angustifolium*.

The larvae hibernate deep in the vegetation while still small, and emerge in March to continue feeding. Pupation occurs in April or May. A small proportion of each cohort have a two-year life cycle and remain as third instar larvae throughout their second summer (Bourn & Warren 1997; Melling 1990). This flexibility may help the species to cope with unpredictable weather during the adult flight period. Adults feed primarily on cross-leaved heath, but hawkweeds *Hieracium/ Hypochoeris* spp., heather *Calluna vulgaris/Erica* spp., tormentil *Potentilla erecta*, and white clover *Trifolium repens* are also used.

The butterfly has declined seriously in England, being lost from half the English counties in which it once was present (Eales & Dennis 1998). Although the rate of decline has slowed, nationwide field surveys suggest that 14% of historic English populations (with a pre-2000 record) are now extinct (A. Suggitt, pers.com.). Much of this decline can be attributed to direct habitat loss through agricultural improvement, drainage and peat cutting (Franco *et al* 2006). In addition to habitat loss, sites have also been degraded by drainage or high intensity burning (Grant *et al* 2012), resulting in the loss of the structure and nectar sources the butterfly requires. Nitrogen deposition is also been suggested as a driver for this change. Population decline has been halted or even reversed in locations where proactive intervention has been put in place.

Butterfly Conservation's presence records for large heath over 2 timeslices, 1960-1990 and post 1990, are shown on the map below (10km grid scale).

Presence of large heath records, 10km².
Source: Butterfly Conservation: Butterflies for the New Millennium.



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Confidence in climate change impacts[28]

Distribution change: **MEDIUM CONFIDENCE** Mechanism: **LOW CONFIDENCE**

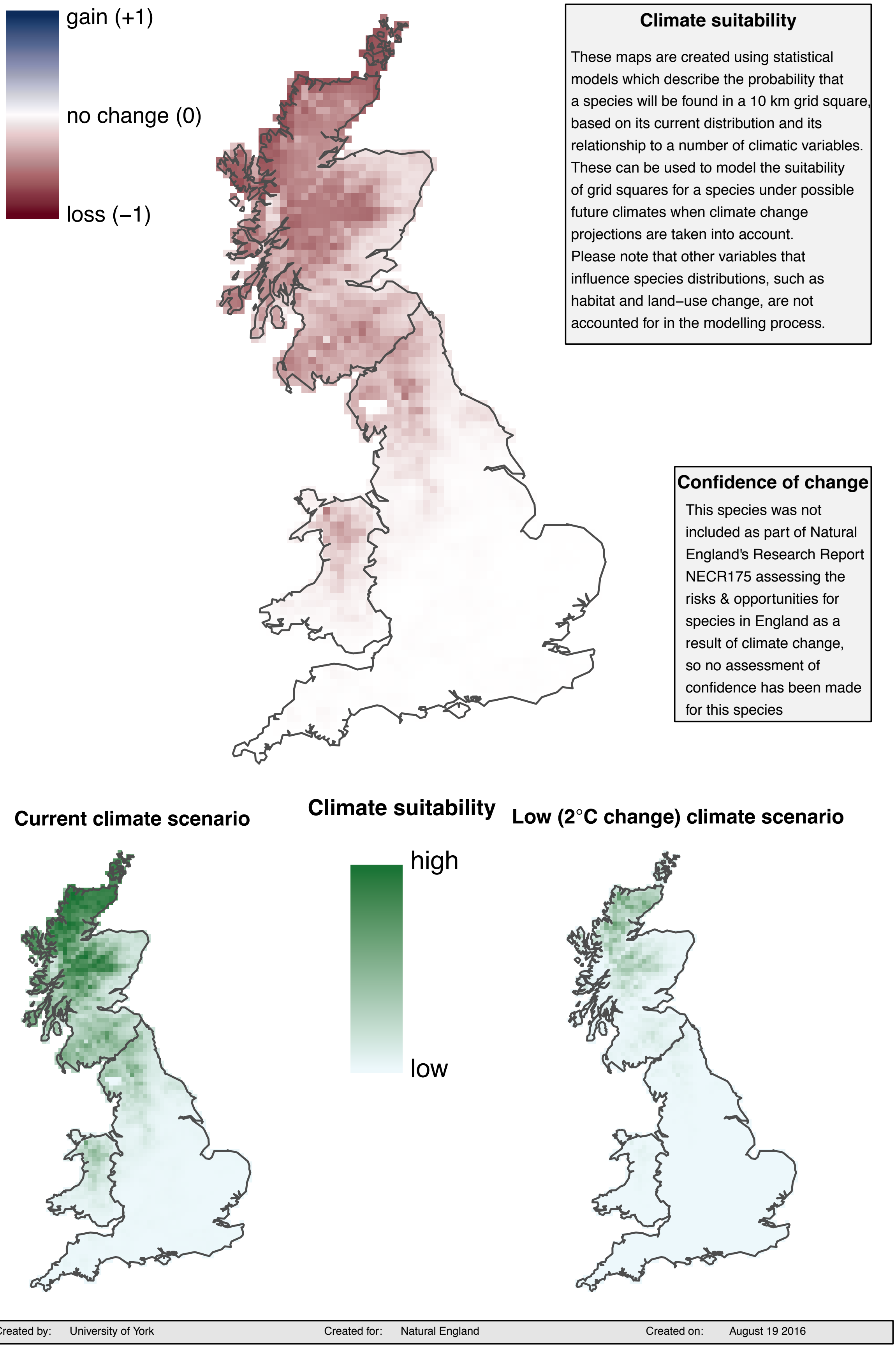
Modelling suggests that in England, the area climatically suitable for the large heath will decline (Berry *et al* 2002; Hill *et al* 2002, Pearce-Higgins *et al* 2015). The quality of the wetland habitat has been shown to be the most important factor affecting the presence of the large heath (Dennis & Eales 1999), and recent work suggests that climate change may directly and indirectly contribute to a degradation of wetland habitat (Weking, Hermann & Fartmann 2013).

The larvae have been shown to be sensitive to raised water levels (Joy & Pullin 1997,1999), suggesting that on some sites prone to flooding the species would be sensitive to changes in the frequency of extreme rainfall events and overall rainfall patterns.

Other potential mechanisms by which climate change could impact on the large heath include competition from other species, losses or gains due to extreme events such as wildfire, and changes in patterns of oviposition.

28 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Projected change in potential distribution of large heath in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015).



Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

Maintaining existing sites in optimum condition and restoring degraded wetland sites that previously supported the species will increase the resilience of populations to climate change. Greater control of site hydrology may be needed to reduce the impacts of climate change on the condition of wetlands, especially for those sites in the south and east of the country projected to have the greatest decline in summer rainfall.

- Manage existing sites to ensure a diverse mix of mire vegetation containing bog mosses, hare's-tail cottongrass and cross-leaved heath.
- Make plans to reduce the risks of and respond to extreme events such as wildfire.
- Restore the hydrology of degraded sites to promote mire and bog development, including by blocking articifical drainage.
- Ensure scrub is controlled to prevent additional pressure on the hydrology of sites.
- Restore sites in close proximity to existing populations, as the species has poor dispersal ability.
- Due to the larval sensitivity to flooding, if the species is present on sites where water level manipulation is used to promote restoration, ensure suitable hare's-tail cottongrass tussocks remain in drier areas, to provide refugial areas that will allow larvae to avoid drowning.
- Monitor known populations to determine the extent of any change, and if it is suspected that climate change is responsible for losses, undertake research to identify the mechanisms responsible. Measures should also be put in place to monitor the impact of adaptation actions.
- Identify additional sites outside the range of natural colonisation for potential artificial reintroduction. Success is likely to be highest in sites in the north of England where changes to patterns of rainfall are unlikely to have an adverse impact on the habitat, or where systems can be put in place to artificially maintain water levels.

Relevant Countryside Stewardship options

SP9 Threatened species supplement

WT10 Management of lowland raised bog

UP3 Management of moorland

UP4 Management of moorland vegetation supplement

Case Study

Heysham Moss large heath Project

Since 2012, Chester Zoo has worked with Lancashire Wildlife Trust (LWT) to restore the large heath to Heysham Moss, where it has not occurred for over 100 years. After acquiring the site in 2004, LWT undertook restoration work to ensure the habitat was suitable for the species. A rearing programme was initiated in 2013, with gravid female butterflies collected from Winnmarleigh Moss. Enclosures at the zoo were constructed to receive the butterflies for egg laying and rearing larvae to pupation. In 2014 and 2015, pupae have been transported to Heysham Moss, and adult butterflies were released when they emerged. A third and final rearing cycle is in progress.

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Little tern
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Little Tern *Sternula albifrons*

Climate Change Sensitivity:	HIGH	Ability to Manage:	MEDIUM
Non climatic threats:	HIGH	Vulnerability:	HIGH

Summary

The little tern has experienced a moderate population decline in recent years and has become concentrated into fewer, larger nesting colonies. Climate change may create opportunities for populations to increase in more northerly areas, although this is dependent on the availability of suitable sand and shingle habitat and food sources. However, it is not clear that their northern range is limited by climate, as there is plenty of apparently suitable habitat within their current range that is not used (probably because there is too much disturbance), and they already breed as far north as Orkney. Little terns nest in areas of sand and shingle close to the shoreline and are therefore vulnerable to dynamic coastal change and coastal squeeze. Consequently, they are likely to be affected by sea level rise and increased storminess leading to more frequent inundation of nest sites. Any loss of habitat which leads to higher concentration on existing sites is likely to exacerbate existing pressures from predation and disturbance.

Little terns are heavily dependent on conservation management, particularly predator control, visitor management, and habitat improvement. Management of existing colonies to increase resilience is likely to be the main approach to adaptation; there are also opportunities to create new areas of inter-tidal habitat to allow new colonies to develop.

Description

The little tern *Sternula albifrons* is one of Britain's rarest breeding seabirds and is the smallest tern nesting in the UK. Little terns winter in West Africa, and return to UK shores in April each year to breed. They are grey and white with a black cap and a distinctive white forehead and yellow, black-tipped beak.

Courtship displays involve chasing and calling in flight, nest scraping and presentation of fish from the male to the female. Nesting usually commences by the end of May, and one to three eggs are laid in a small scrape in sand or shingle. The eggs are incubated for three weeks. Hatching is usually from mid-June onwards. The chicks stay in the area of the nest scrape for the first 48 hours, after which they will move, possibly finding shelter from the sun or wind behind debris on the beach or small patches of vegetation. The chicks take up to three weeks to fledge. Both parents feed the chicks during this time, calling to locate them on the beach when they return from fishing nearby.

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Ecology and distribution

Little terns are found predominantly on low lying, soft coasts in southern and eastern England, with a concentration in East Anglia. There is a large colony in North Wales which is also a post-breeding staging post and there is a population in south Cumbria. In Scotland, the population is less well monitored but is well distributed over south and west Scotland, with just a few known colonies in North and East Scotland. The most northerly colony is on Orkney.

Little terns nest on open coastal sites, usually choosing flat or gently sloping sand or shingle beaches, shingle ridges, spits and islands. They choose sites which are close to the high tide line and which are subject to change through winter storms. Unlike the other tern species breeding in the UK, they do not forage far for their food, often just off-shore from the colony, where they catch predominantly small fish, and also shrimp and insects from the surface. The chicks are fed preferentially on small sand eels and clupeids (herring family). The availability of such prey close to the colony is an important factor for breeding success.

The UK population is estimated at 1,900 breeding pairs (last census), which represents 9.7% of the biogeographic population and 2.2% of the world population. However, current monitoring results and the 18% decline seen between 2000 and 2015 (Haynow *et al* 2017), now suggest a population of around 1,600 pairs.

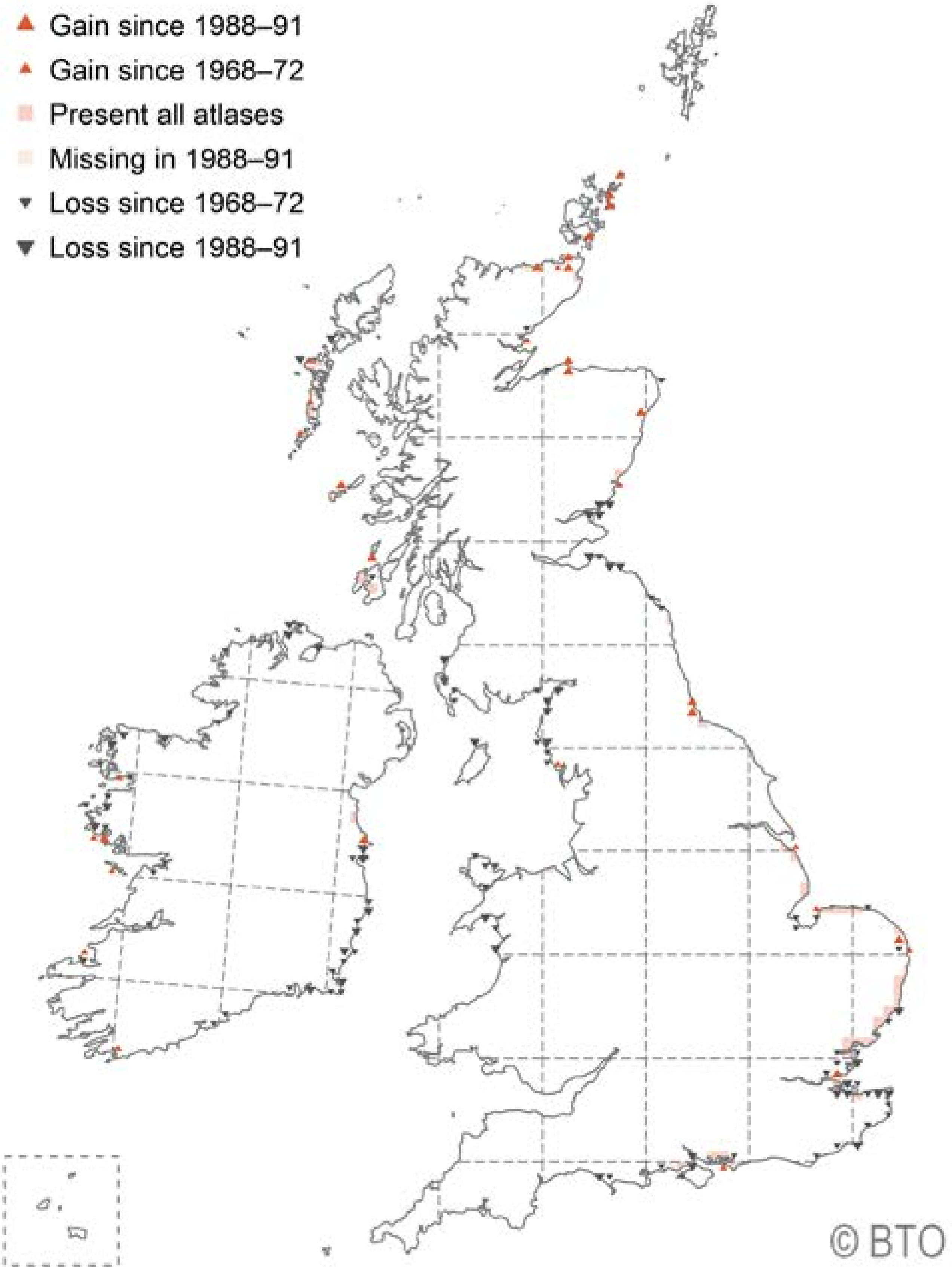
The little tern's UK conservation status has been assessed as Amber in Birds of Conservation Concern 4, for moderate long-term breeding range decline and breeding localisation. At a European level, it has experienced continued moderate decline and is listed as a category 3 Species of European Conservation Concern (SPEC 3).

Table: Little tern population data

Historic Census data	Operation Seafarer (1969-70)	Seabird Colony Register (1985-88)	Seabird 2000 (1998-2002)
UK population estimate (Apparently Occupied Nests)	1,589	2,517	1,927
Change since previous census	n/a	+58%	-23%

Minimum Pairs / AONs / AIAs (reported colonies in the UK)	2013	2014	2015	2016	2017
Rare Breeding Birds Panel	1,553	1,521	1417		
Annual Little Tern Newsletter			1,296	1,302	1,404

Historic changes in the distribution of the little tern
(reproduced with permission of the BTO, from Balmer *et al* 2013)



Confidence in climate change impacts[29]

Distribution change: **HIGH CONFIDENCE** Mechanism: **MEDIUM CONFIDENCE**

This section considers the potential impacts of climate change on the UK summer breeding populations of little terns. There is little knowledge about the current threats and levels of mortality in the wintering grounds of West Africa.

The little tern is regarded as having a moderate opportunity for expansion, with populations in the northern parts of its range likely to increase in abundance (Pearce-Higgins *et al* 2015).

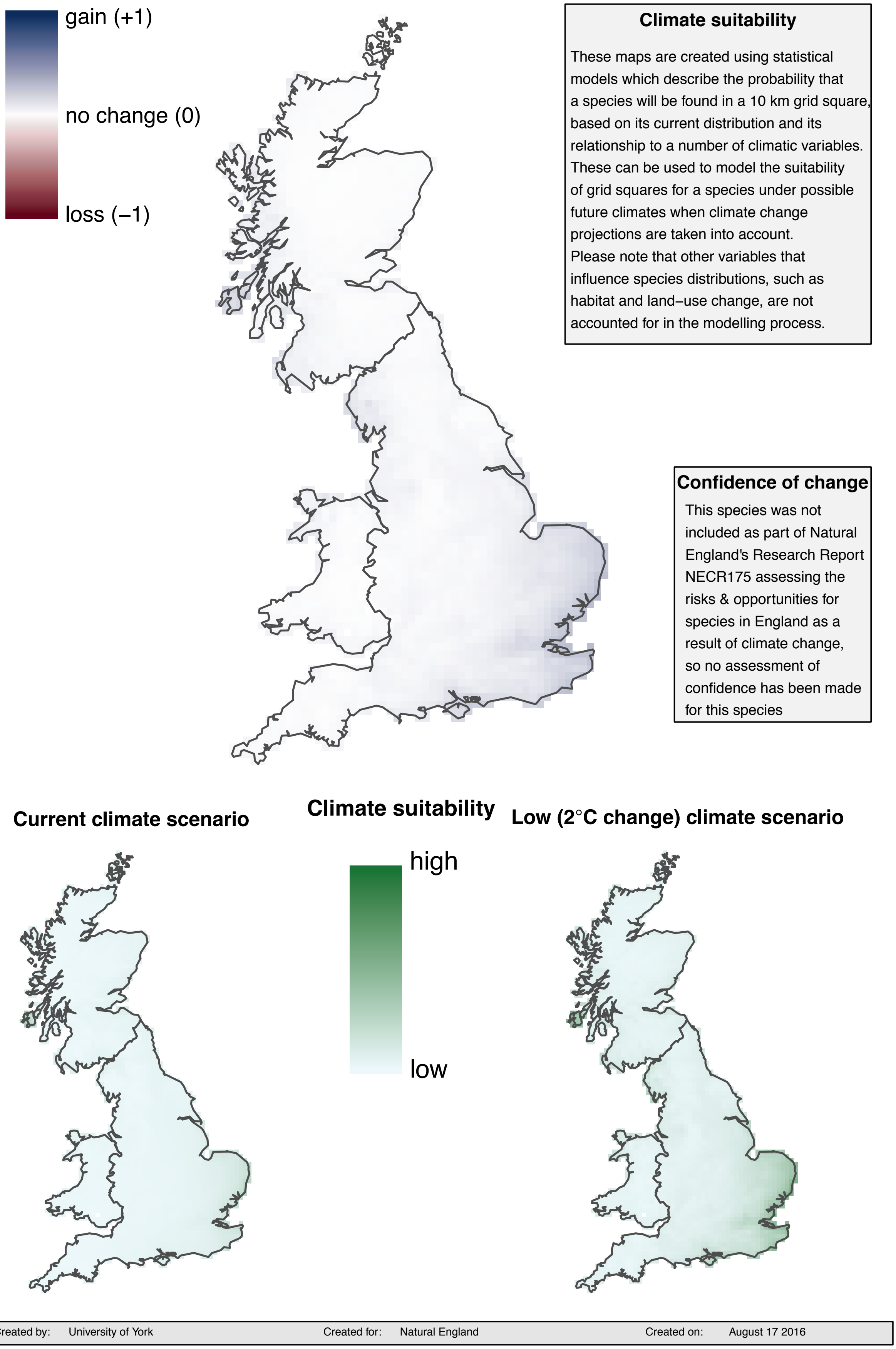
Climate envelope modelling suggests that Britain's climate will become more suitable for a range of southerly distributed seabirds, including the little tern, but this assumes no climate-induced effects on sand eels and other prey species. Although little terns may become more abundant in the north of their range, with climate change food availability could limit any potential expansion. Little terns could be affected by the impact of rising sea temperatures on populations of sand eels and clupeid fish. Unlike other tern species, they habitually feed very close to their nesting sites during chick rearing. The ability to mitigate this is likely to be limited to creating and restoring sites where prey availability is sustained.

Little terns are vulnerable to natural processes of coastal change as they nest on open sand and shingle close to the high tide. The risk of habitat loss will be exacerbated by sea level rise which, together with more frequent storm events, could mean that nesting sites become more vulnerable to inundation. This can mitigated in the longer-term by creating or restoring sites that are more sustainable, either within the coastal zone or immediately landward of current sea defences.

Little terns are also vulnerable to non-climatic threats, especially predation, human disturbance, and competition from other species (Ratcliffe, Pickerel & Brindley 2000). While these can often be managed by restricting visitor access, fencing, and direct predator control, their impact could be exacerbated if climate change results in habitat squeeze with little tern colonies occurring in areas where these conflicts are more likely to arise.

29 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Projected change in potential distribution of little tern in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015).



Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

Little terns have benefitted from management for a number of decades and are deemed a conservation dependent species that has experienced a moderate decline and a concentration into fewer, larger colonies. Management generally involves colony protection and habitat creation.

Loss of sites and population decline would have been greater without this continued intervention, especially around southern and eastern coastlines. Increased input in the form of wardens and temporary fencing has improved nesting activity and breeding success, and increased public awareness has reduced recreational disturbance.

There are still management issues with regard to increased recreational pressure and predation 'honey-pot' effects, as the effect of coastal change, disturbance and other pressures has led to the development of fewer but larger colonies.

Future management options include increasing the rate at which inter-tidal habitat is re-created, particularly brackish wetlands and saline lagoons containing islands, assuming that they might take to such islands more than they have done in the past. Consideration should be given to re-charging areas of eroding and over-topped inter-tidal habitat, the loss of which for breeding habitat is exacerbated by climate change factors, using dredging material e.g. at Horsey Island, Essex (Allcorn 2003), and including nesting islands within managed realignment and regulated tidal exchange projects, such as at Wallasea and Medmerry.

As little terns have such specific breeding habitat requirements (sand or shingle beaches or islands free from human disturbance and mammalian and seabird predation), opportunities for range expansion may be limited. Consequently, reducing levels of human disturbance and predation pressure on existing sites is likely to be critical.

Relevant Countryside Stewardship options

FG7: Anti-predator combination fencing.

FG8: Anti-predator temporary electric fencing.

CT2: Creation of coastal sand dunes and vegetated shingle on arable land and improved grassland.

CT4: Creation of inter-tidal and saline habitat on arable land.

CT5: Creation of inter-tidal habitat and saline habitat by non-intervention.

FM2: Major preparatory works for Priority Habitats (creation and restoration) and Priority Species.

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Case Study

Little Tern Recovery Project

A five year partnership project supported by the EU LIFE+ Nature fund which included actions to enhance management and restore/create habitat.

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Mountain bumblebee
© Dave Goulson

Mountain (Bilbury) Bumblebee
Bombus monticola Smith.

Climate Change Sensitivity:	HIGH	Ability to Manage:	LOW
Non climatic threats:	MEDIUM	Vulnerability:	HIGH

Summary

The mountain bumblebee is a cool-loving species of the uplands. In the past it was widespread in north and western Britain, but its population has declined. The main causes of this decline are thought to be related to habitat loss and degradation, both of which reduce or eliminate the flowering plants it relies on. However, the more rapid recent decline is consistent with that projected under a warming climate, and projections suggest a further contraction of suitable climate space.

Maintaining a mosaic of suitable habitat that includes upland heathland and hay meadows that support bilberry and legumes such as clover and birds-foot trefoil will be a key adaptation response.

Description

The queens, workers and males of the mountain bumblebee all have two yellow bands on the thorax but none on the abdomen. The yellow is bright and often straw-coloured. However, the rear band on the thorax is less pronounced. The orange-red tail colouring extends over more than half of the abdomen. Sexes are similar in colour, but males have yellow facial hair.

Ecology and distribution

The mountain bumblebee is associated with mountain and moorland habitats, including blanket bogs, upland heath and upland hay meadows, and is found in western and upland areas of England, including Dartmoor, Exmoor, the Peak District, and the North York Moors. There is evidence to suggest it needs access to grassland and heathland habitats, and it has a strong affinity with areas rich in bilberry *Vaccinium spp*, its preferred pollen source. It is found closer to sea level in northern England.

Queens emerge from hibernation in April and search for suitable nest sites, which are frequently found at the base of bilberry or heather plants. Once identified, the queen makes a single entrance chamber. Within this she forms a wax pot which she fills with nectar, and next to it a wax covered lump of pollen (usually from bilberry or *Salix* (Goulson pers. com), inside which she lays between 8-16 eggs.

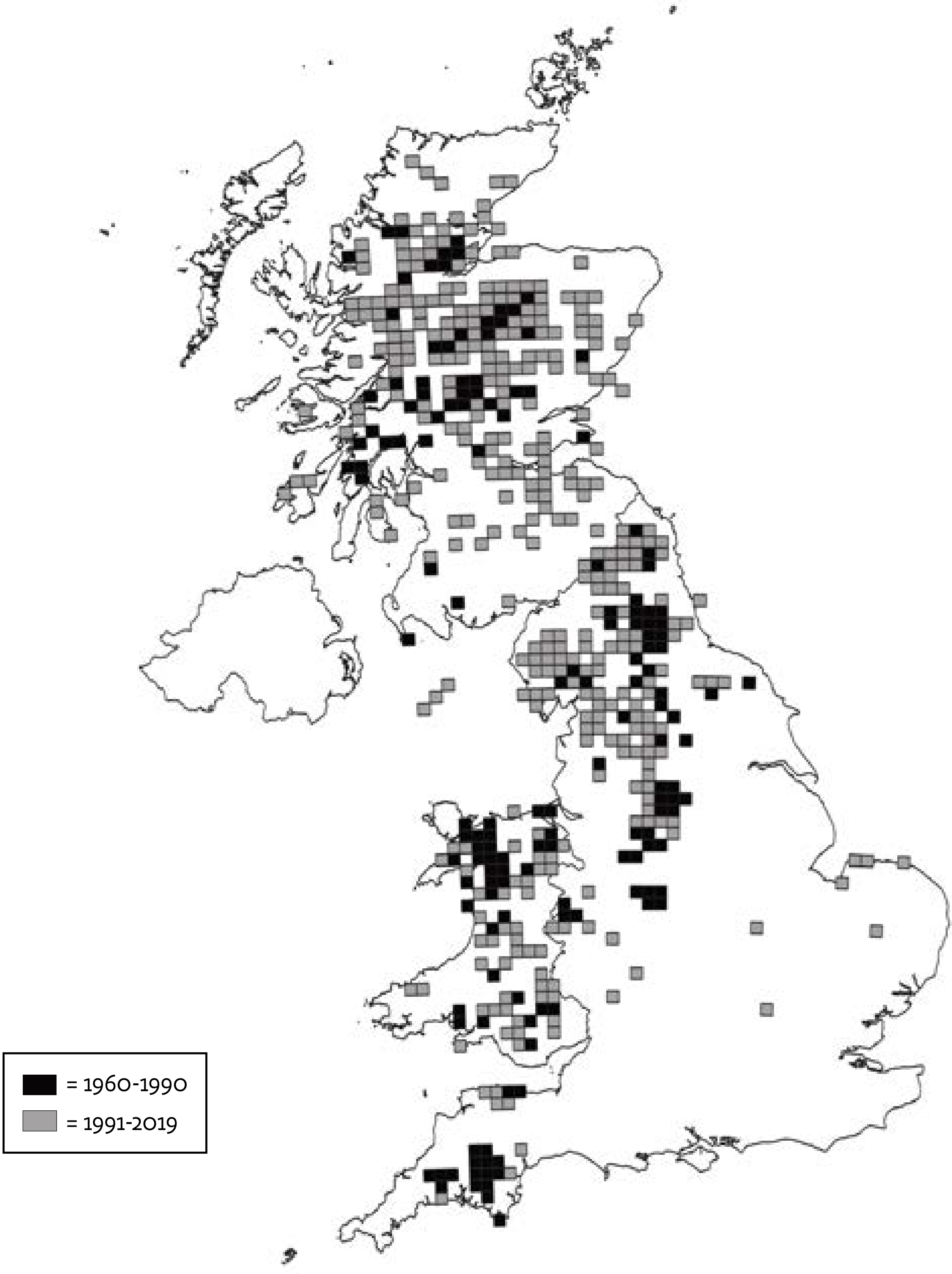
Larvae hatch in a few days and begin feeding on the pollen. After a couple of weeks the larvae spin a cocoon and pupate. The first batches of adults are all female 'worker' bees. Some of these will stay behind to help rear the next batch of workers but most will leave the nest and forage. Workers can be seen from May onwards visiting bilberry flowers, but also sallow *Salix spp*, bramble *Rubus fruticosus* agg, raspberry *Rubus idaeus*, bell heather *Erica cinerea*, and legumes such as clover *Trifolium* spp and birdsfoot trefoil *Lotus corniculatus*.

The cycle continues until around June, when the queen switches from producing workers to a mix of males and new queens. These generally emerge between July and August. The young queens feed on pollen and nectar to build up their energy reserves. Mating takes place at this time. Once mated the new queens locate a suitable hibernation site, usually loose soil in which they can burrow and form a small chamber in which to overwinter.

In Europe it is absent from isolated suitable habitat suggesting that is has relatively poor dispersal or requires large patches to persist (Rasmont *et al* 2015).

Bees, Wasps and Ants Recording Society (BWARS) and Bumblebee Conservation Trust (BBCT) presence records for mountain bumblebee are shown on the map below (10km grid scale).

Presence of mountain bumblebee records, 10km[2].
Maps contain BWARS and BBCT BeeWalk data reproduced with permission.



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Confidence in climate change impacts[30]

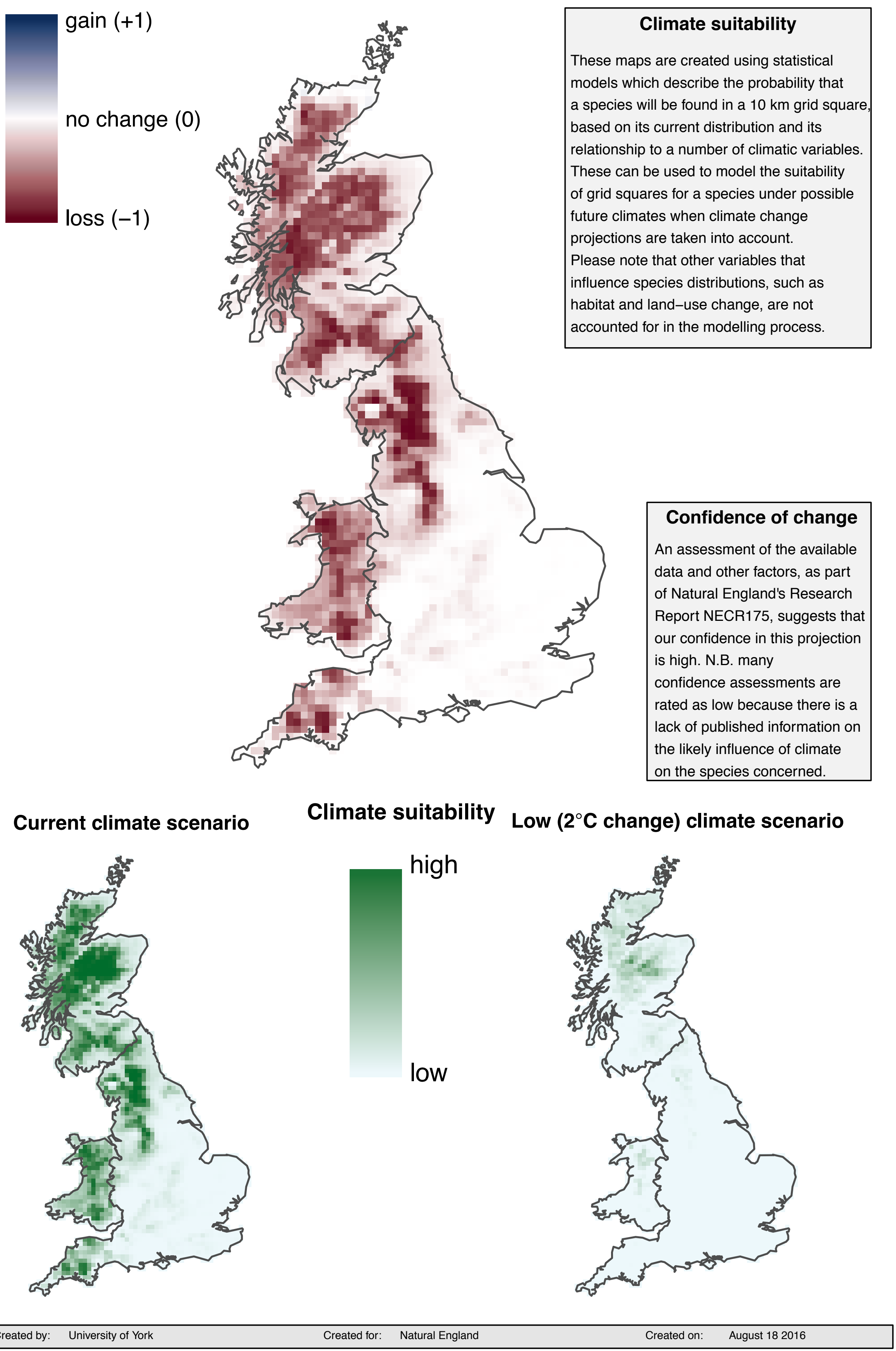
Distribution change: MEDIUM CONFIDENCE Mechanism: LOW CONFIDENCE

Recent changes in the distribution of the mountain bumblebee in England and across its range are consistent with a warming climate. These changes consist primarily of an up-slope contraction of its presence (Manino *et al* 2007). This suggests that changes in temperature are the main driver of change, although the mechanism is unknown (Iserbyt & Rasmont, 2012). Modelling suggests a further contraction of its range (Rasmont *et al* 2015). Anecdotal evidence suggests that recent warmer springs are leading to early emergence of the queens in March and April, which makes them susceptible to late frosts (Evans & Potts 2013).

The species has also been shown to have lower heat tolerance than species that inhabit lower altitudes (Martinet *et al* 2015) making it more susceptible to climate change driven warming. Warming may also lead to colonisation by more competitive species (Pradervand *et al* 2014; Goulson *et al* 2005).

30 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Projected change in potential distribution of mountain bumblebee in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015).



Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

- Manage grazing to ensure sites support healthy populations of bilberry and a wide range of nectar sources, including clover and birdsfoot trefoil (Welch 1998).
- Ensure grazing regimes support the flowering of favoured plants throughout the season; bilberry and sallow in spring; birdsfoot trefoil, clovers, raspberry and bramble in early to mid-summer, and bell heather in mid to late summer.
- Within existing sites, identify and protect areas that have the potential to act as climate change refugia, such as sites with topographic variation and north facing slopes.
- Restore, maintain or create a mosaic of suitable habitat around existing sites, especially upslope from these where possible, including upland heathland that supports bilberry, *Salix* and *Erica*, and hay meadows that support legumes such as clover and birds-foot trefoil.
- Monitor known populations to determine the extent of any change, and where possible to identify the mechanisms driving this change. This is especially important at sites at the southern margins of its range where the impacts of climate change are likely to be most apparent.
- Identify potential reintroduction sites in areas where the climate will remain suitable and that are outside the species' limited natural dispersal range.
- Undertake further research to identify the mechanisms driving climate change losses; and to understand colonisation processes, in order to improve the targeting of habitat restoration and creation.

Relevant Countryside Stewardship options

UP1 Enclosed rough grazing

UP3 Management of moorland

UP6 Upland livestock exclusion supplement

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Mountain ringlet
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Mountain ringlet *Erebia epiphron* Knoch.

Climate Change Sensitivity:	HIGH	Ability to Manage:	LOW
Non climatic threats:	LOW	Vulnerability:	HIGH

Summary

The mountain ringlet is found in mountainous areas of England and Scotland, generally between altitudes of 450 and 700 metres above sea level. Difficulties in surveying this species means it is probably under-recorded within its range, particularly at remote sites in Scotland.

There is evidence that the mountain ringlet has been lost from lower altitude sites in a pattern consistent with a warming climate (Franco *et al* 2006, A. Suggitt pers. Comm.). Potential climatic drivers of observed changes in the mountain ringlet's distribution are poorly understood, but may include increased mortality of overwintering larvae due to warmer winters or higher summer temperatures exceeding the thermal tolerance of developing eggs and early instar larvae.

Under projected climate change, the distribution of mountain ringlet is likely to contract further with lower altitude and south facing sites most at risk.

Altering the management of sites to promote both the host plant and nectar sources, together with the creation of a range of suitable microclimates through appropriate grazing management, may increase resilience to a degree.

There may be opportunities to use local translocation to establish new colonies within the Lake District to increase population size in potential refugia.

Description

The butterfly is the smallest "Brown" (*Nymphalidae)* family found in England. It has a hairy body and dark brown wings, both of which are adaptions to cold conditions. Its wings have rows of black-centred orange eyespots. The female is somewhat larger than the male, and the bands or rings are paler. Scottish individuals are larger than those found in the Lake District. They also tend to have larger eyespots and pupils, although there is considerable variation within each region.

Ecology and distribution

The mountain ringlet is the UK's only truly montane species of butterfly. In England, it is restricted to a relatively small number of colonies in the Lake District. There are also populations in the West and Central Highlands of Scotland, with isolated populations in the Cairngorms. The English and Scottish populations are genetically different and are not likely to have interacted for thousands of years (M. Minter, pers. comm.). Field surveys suggest that 26% of historic English populations (with a pre-2000 record) are now extinct (A. Suggitt 2019 pers. comm.; Franco *et al* 2006). (The localised distribution of the butterfly means that these changes are not picked up at the 10km^2 resolution of the national distribution maps.)

It is most abundant in areas with a combination of mat-grass *Nardus stricta* and abundant nectar plants. Heath bedstraw *Galium saxatile*, meadow buttercup *Ranunculus acris*, and tormentil *Potentilla erecta* are preferred in heavily grazed sites, but where grazing permits a wider range of flowering plants are also utilised, such as thyme, hawkweeds and marsh thistle.

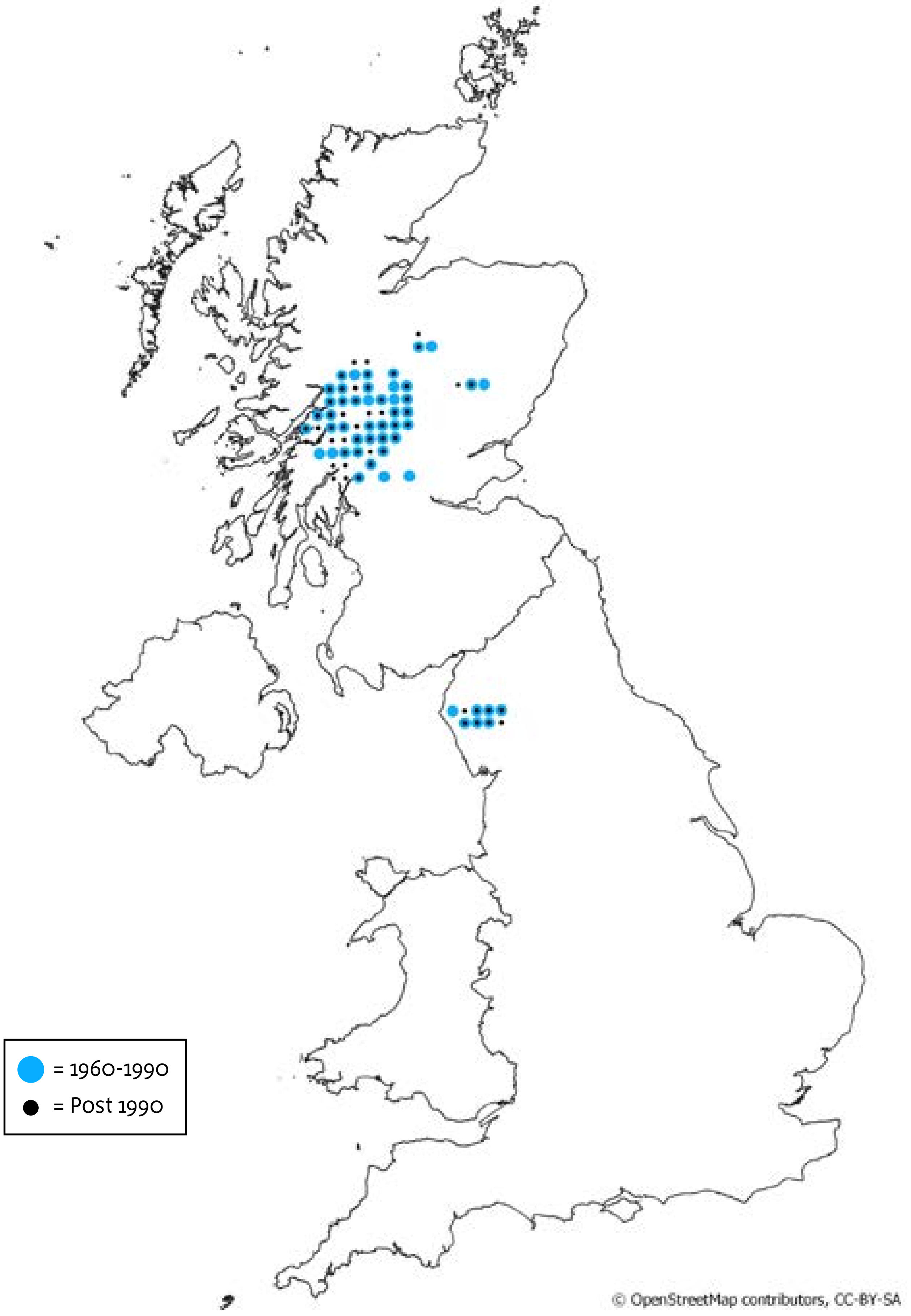
Eggs are laid singly and close to the ground on the dead leaves of mat-grass or sheep's-fescue *Festuca ovina* (Ewing *et al* 2019) although other plants are occasionally used. Swards with a high abundance of the main host plants are preferred. The larvae feed at night and hide by day at the grass base. The larvae hibernate within the sward as third instar caterpillars during late August or September. After resuming feeding in the spring, pupation occurs in late May or June on the ground or in grass tussocks. In captivity the species has been shown to have the potential to have a two year life cycle, which could act as an adaption to potential poor summer conditions preventing mating.

The short flight period often extends from the middle of June to late July, and varies with altitude. Warmer, low lying sites can see individuals on the wing in May, while at cooler, high altitude sites, the flight season can extend well into August. There are also marked differences in the peak emergence from year to year. Adults are relatively short lived and their activity is highly dependent on temperature. In cooler conditions, flights are confined to sheltered locations rich in nectar plants, whereas in warmer conditions, adults may be found more widely across south-facing slopes.

The mountain ringlet is found in discrete colonies. Adults tend to remain sheltered deep in grass tussocks in overcast and cool conditions and only fly in bright sunshine. They are relatively sedentary, and populations on different mountain ranges are unlikely to mix.

Butterfly Conservation's presence records for mountain ringlet over 2 timeslices, 1960-1990 and post 1990, are shown on the map below (10km grid scale).

Presence of mountain ringlet records, 10km².
Source: Butterfly Conservation: Butterflies for the New Millennium.



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Confidence in climate change impacts[31]

Distribution change: **HIGH CONFIDENCE** Mechanism: **LOW CONFIDENCE**

The loss and high turnover of mountain ringlet colonies from lower altitude sites is consistent with adverse impacts associated with a warming climate (Franco *et al* 2006, Suggitt 2019 pers. comm.). The mechanism driving the decline remains uncertain. One potential mechanism via which climate change may impact mountain ringlets is via reductions in snow cover leading to increased mortality of overwintering larvae due to greater exposure to cold (Vrba *et al* 2016, Ewing 2019 pers. comm). Alternatively, periods of unseasonal mid-winter warming, followed by resumption of cold conditions, may disrupt hibernation of mountain ringlet larvae, also impacting larval survival, or spring warming may disrupt the synchrony between the emergence of males and females (Konvička *et al* 2016).

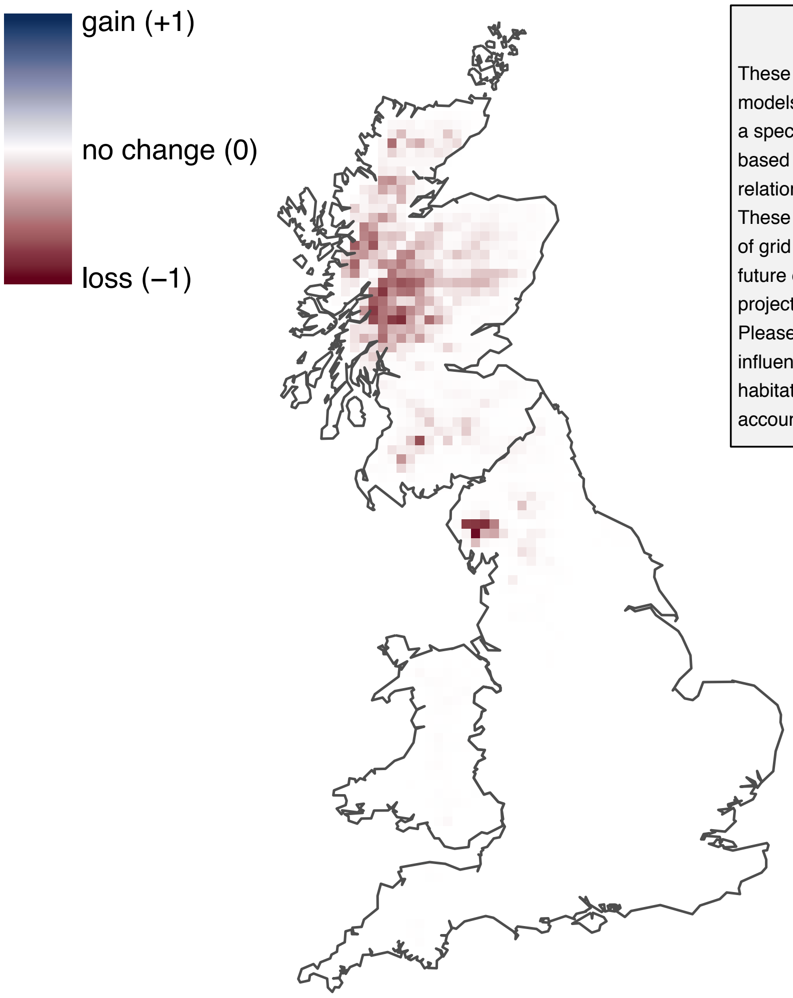
The species' preference for warm sites for oviposition suggests that hotter summer temperatures are unlikely to be the direct cause of its decline to date, however with increased warming the temperature of currently preferred oviposition sites may become increasingly unsuitable and/or leave these sites more prone to drought.

Under projected climate change, the distribution of the mountain ringlet is likely to contract further, with lower altitude and south facing sites most at risk.

Its altitude-restricted distribution means that the potential area of suitable habitat for mountain ringlet in England will continue to decline. A limited number of higher altitude locations (with sufficient shelter from the wind) could become more climatically suitable, but this will be more than offset by losses at lower altitude.

31 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Projected change in potential distribution of mountain ringlet in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015).

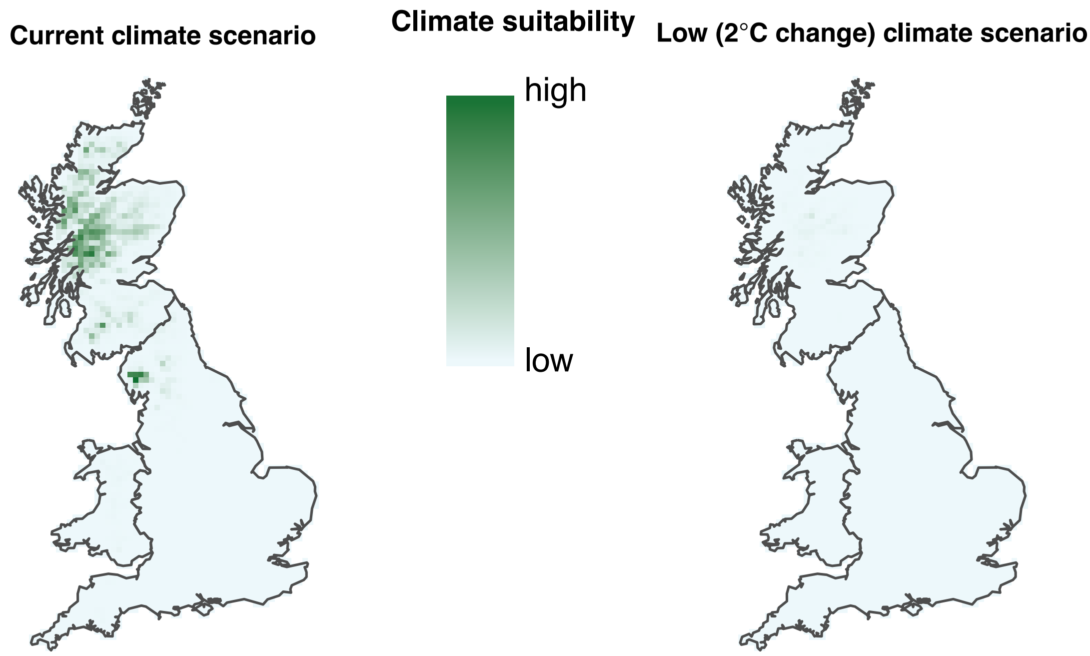


Climate suitability

These maps are created using statistical models which describe the probability that a species will be found in a 10 km grid square, based on its current distribution and its relationship to a number of climatic variables. These can be used to model the suitability of grid squares for a species under possible future climates when climate change projections are taken into account. Please note that other variables that influence species distributions, such as habitat and land–use change, are not accounted for in the modelling process.

Confidence of change

This species was not included as part of Natural England's Research Report NECR175 assessing the risks & opportunities for species in England as a result of climate change, so no assessment of confidence has been made for this species



Created by:	University of York	Created for:	Natural England	Created on:	August 19 2016

Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

The simultaneous loss of this species from sites at lower altitude and the observed preference for warm oviposition sites presents a challenge in developing adaptation options. Changes to management to ensure the availability of a suitable swards and oviposition sites across a broad topographic and altitudinal range may increase chances of maintaining the species at its range margin in England.

- Ensure optimum management of existing sites through grazing to encourage a sward that supports high populations of mat-grass and sheep's fescue, moderate levels of litter and a wide range of nectar sources. Avoid over- or under-grazing.
- In south-facing and lower altitude sites, manipulate management to promote a broad range of microclimates from short to taller swards, potentially accepting the presence of scrub to create shaded areas.
- Within existing sites, identify and protect areas that have the potential to act as climate change refugia, such as sites with topographic variation or close to flushes or streams.
- Identify potentially suitable higher altitude locations and manage to promote suitable swards and connectivity with existing populations to promote natural colonisation.
- Monitor known populations to determine the extent of any change and, where possible, seek to identify the mechanisms driving change. Monitor the impact of any adaptation actions.
- Undertake research to understand colonisation processes, to improve the targeting of habitat restoration and creation.
- Consider local translocation within the Lake District to establish new populations in potentially suitable but currently unoccupied sites with the potential to become refugia where natural colonisation is not likely.
- The English sub-species *E. e. mnemon* found in the Lake District is distinct from the Scottish sub-species *E. e. scotica* in the Scottish Highlands. This should be recognised prior to consideration of translocation outside its current natural range.

Relevant Countryside Stewardship options

UP3 Management of moorland

UP4 Management of moorland vegetation supplement

SP9 Threatened species supplement

Case Studies

Farming with nature at RSPB Haweswater

The RSPB has carried out research on mountain ringlets at its reserve in Haweswater, and at other sites in the Lake District and Scotland, to better understand the autecology of the mountain ringlet, particularly in relation to patterns of habitat selection. With an improvement knowledge of the species' basic habitat requirements, the project then hopes to develop options to improve the likelihood of this species successfully adapting to climate change.

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Northern brown argus
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Northern brown argus *Aricia artaxerxes* F.

Climate Change Sensitivity:	HIGH	Ability to Manage:	MEDIUM
Non climatic threats:	MEDIUM	Vulnerability:	HIGH

Summary

The northern brown argus has been declining over the last thirty years due to loss of habitat and changes in land management. Its range has also contracted in a manner consistent with recent warming. The threats from climate change are exacerbated by its poor dispersal ability and potential hybridisation with the brown argus *A. agestis*, the range of which is expanding.

Altering the management of sites through changes to the timing and intensity of grazing and the management of scrub are likely to mitigate on-site vulnerability to a degree, but off-site action to promote natural dispersal will also be required to safeguard the species in the UK. Translocation to establish colonies in areas where the climate will remain more suitable and that are beyond the natural dispersal ability of the butterfly should be considered.

Description

The northern brown argus is a small butterfly with a silvery appearance when in flight. When basking, it is a deep chocolate brown, fringed with white. Orange spots just inside this white fringe are clearly defined and bright orange on the hind wings, but relatively pale on the forewings.

The sexes can be distinguished by the orange spots around the edges of the upper wings, which extend to the leading edge of the forewing in the males, while in the females the spots are very pale or absent at this point.

Colonies in northern England are of the subspecies *salmacis*. The central spot on the upper side of the forewings in this sub-species is dark brown or black sometimes with a pale white edge to the spot. This differentiates it from the subspecies *artaxerces* found in Scotland, which has a distinctive white spot on the upper side of the forewings.

Ecology and distribution

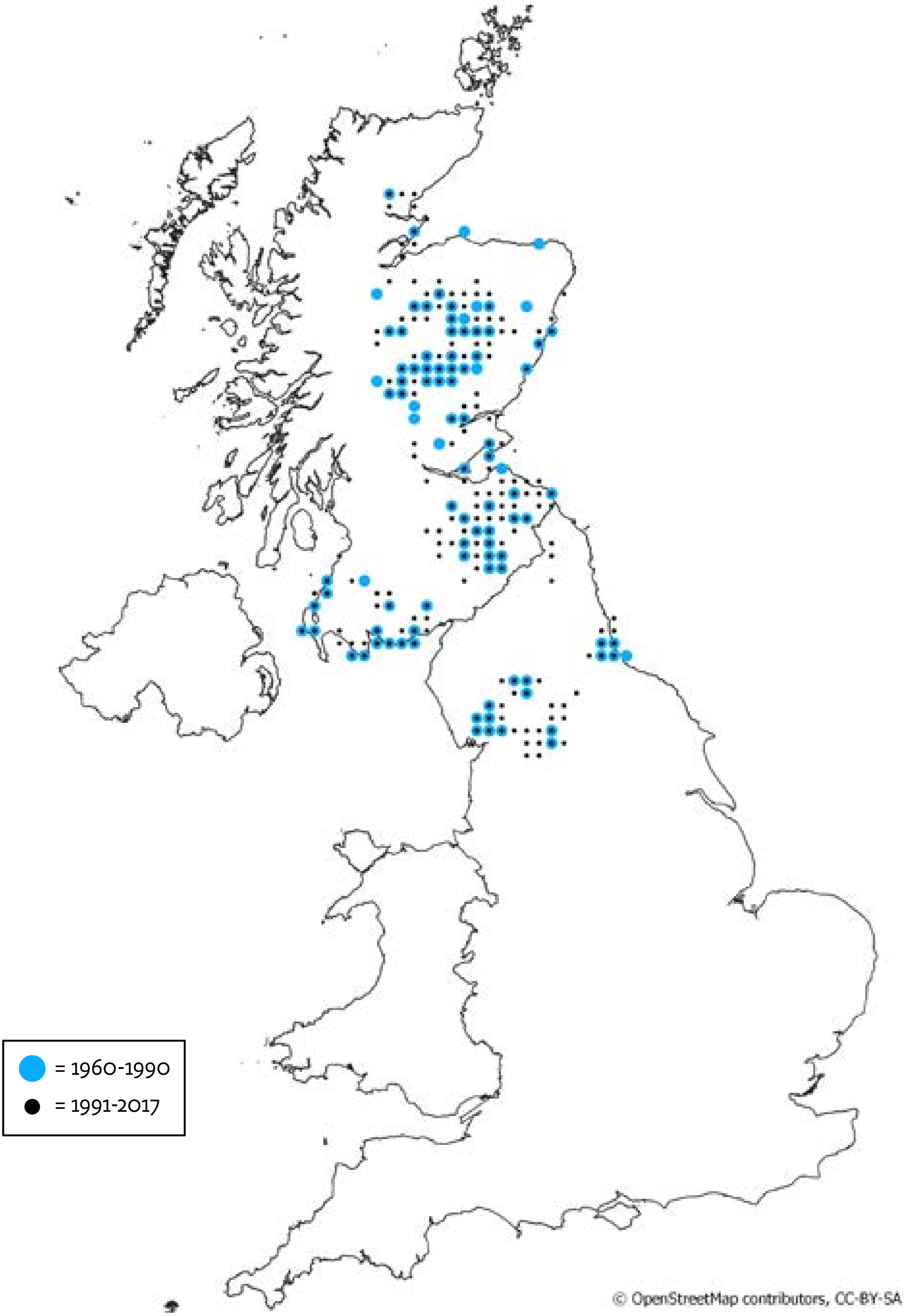
The northern brown argus occurs on thin soils that are usually south-facing and up to 350m in altitude. It is relatively widespread, but localised in northern England and Scotland. It is found in well-drained, unimproved calcareous grasslands and limestone outcrops or pavement which support common rock-rose *Helianthemum nummularium*.

The species is single brooded, with adults typically flying from early June until mid-August, with a peak in numbers from late June to mid-July. The flight period varies considerably between years and between regions. The eggs are laid singly on the upper side of common rock-rose leaves. Females select plants that have fleshy leaves and are typically growing in sheltered situations. They lay in swards of varying heights from 1-30cm, but most frequently in medium (6-10cm) and taller (over 10cm) swards. The young larvae feed on the underside of leaves, leaving the upper surface intact. They hibernate at the base of the food plant or on the ground. The larvae start basking in early spring, before recommencing feeding. They possess ant-attracting organs on the abdomen and are sometimes attended by ants. The larvae pupate in late May, often lying on the ground on a silken mat, or attached by silk threads amongst the vegetation.

The butterfly has been lost from many sites over the last thirty years due to both intensification and under-management (Franco *et al* 2006). It forms discrete colonies on relatively small habitat patches, and because adults have a very limited colonising ability, extinctions are more common on small, isolated sites. This has resulted in increased fragmentation of the remaining sites, leading to further losses. Much of this change is masked in the 10km distribution maps due to an increase in survey intensity leading to the identification of previously unrecorded colonies.

Butterfly Conservation's presence records for northern brown argus over 2 timeslices, 1960-1990 and post 1990, are shown on the map below (10km grid scale).

Presence of northern brown argus records, 10km².
Source: Butterfly Conservation: Butterflies for the New Millennium.



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Confidence in climate change impacts[32]

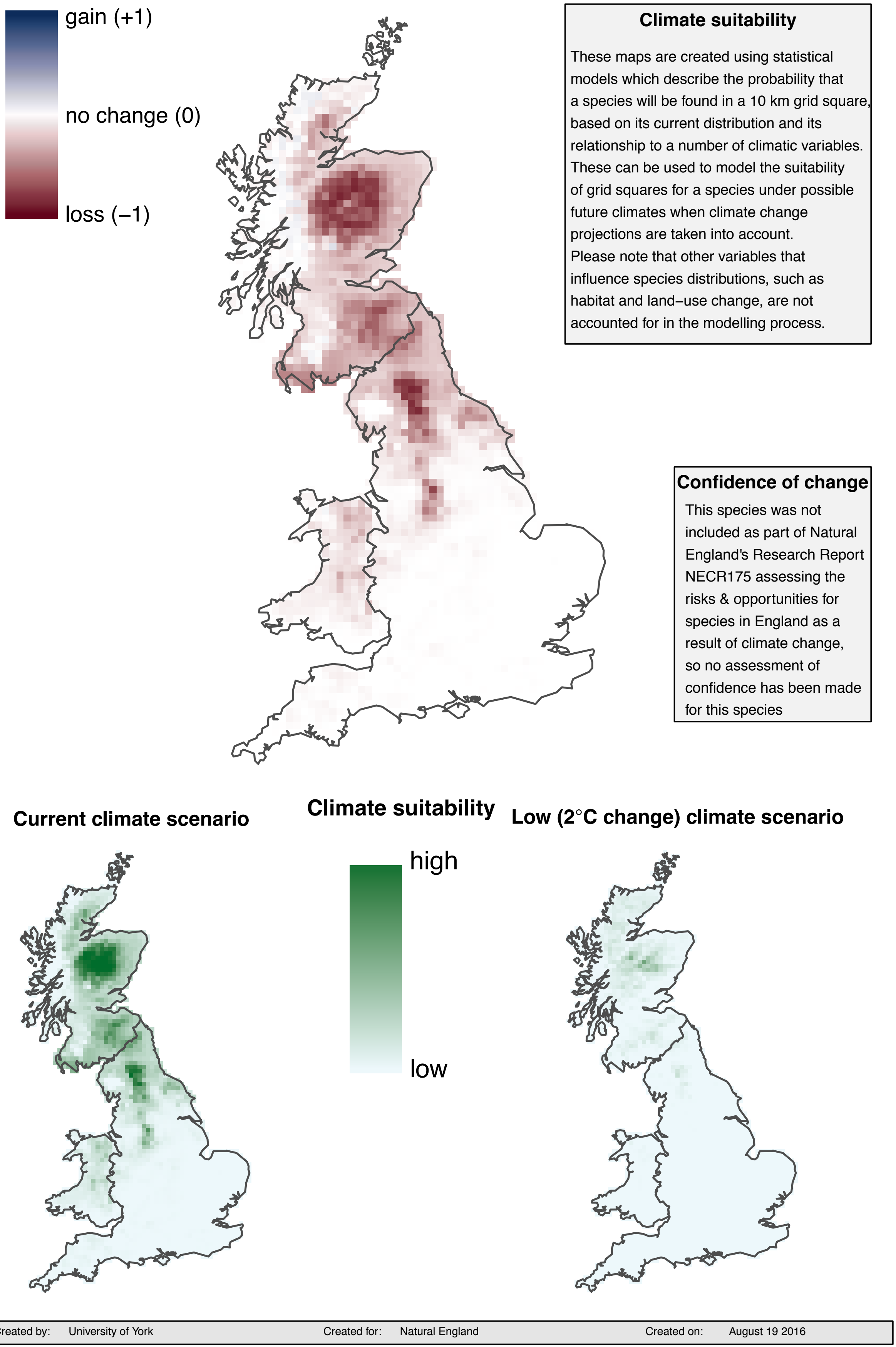
Distribution change: **HIGH CONFIDENCE** Mechanism: **LOW CONFIDENCE**

Changes in the distribution of the northern brown argus over the last thirty years are consistent with a warming climate (Franco *et al* 2006), although the precise mechanisms causing these changes are unclear. Nationwide field surveys suggest that 28% of historic English populations (with a pre-2000 record) are now extinct (Suggitt 2017, pers. com.). It appears to be particularly adversely impacted by warm winters (McDermott Long 2017). It is likely that the distribution of the butterfly will continue to contract significantly as the climate warms, with a decline in the suitability of many southern sites. Such a shift suggests that changes to the management of existing sites will be required to ensure or prolong their persistence. The poor natural dispersal ability of the butterfly is likely to prevent it colonising areas of the country that become more climatically suitable.

The butterfly is also threatened by the northward expansion of the brown argus *Aricia agestis* and the potential for hybridisation (Mallet, Wynne & Thomas 2010). The zone of potential hybridization now includes all extant English populations of northern brown argus, meaning that introgression[33] is a possibility at any English site. The consequences of this for the long-term persistence of the *artaxerxes* taxon are unclear at present, although given that the hybrids are known to be viable, extinction of the taxon in England should be considered possible. This should be monitored, as the adaptation options described below (the first three in particular) are better focussed on areas where *A. agestis* is not present and is not predicted to colonise (at least in the near future).

32 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.
33 the transfer of genetic information from one species to another as a result of hybridization between them and repeated backcrossing

Projected change in potential distribution of northern brown argus in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015).



Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

The current range contraction, coupled with the butterfly's preference for laying its eggs in medium to tall swards, suggests that reductions in the availability of cooler microclimates may be a factor in its decline. Changes in management to provide a taller sward or suitable habitat on north facing slopes will help to ensure the availability of cooler oviposition sites and may offer a form of adaptation.

- Ensure optimum management of existing sites through grazing to provide a medium to tall sward that supports populations of common rock-rose and a wide range of nectar sources.
- In southern and lower altitude sites, manipulate management to promote areas with a cooler microclimate by creating taller swards and using scrub to produce shaded areas.
- Within existing sites, identify and protect areas that have the potential to act as climate change refugia, such as areas with topographic variation and north facing slopes. Take action to increase the area of suitable habitat around existing small populations by restoring or creating species rich calcareous grassland and managing scrub on existing grassland sites.
- Monitor known populations to determine the extent of any change and, where possible, seek to identify the mechanisms driving change. Measures should also be put in place to monitor the impact of any adaptation actions.
- Identify potential reintroduction sites in areas where the climate will remain suitable and that are outside the range of natural dispersal, and where *A. agestis* is not likely to colonise in the near/medium future.
- In the southern part of its range hybridisation with the brown argus *A. agestis* is likely to occur. Conservation objectives at the site level will need to reflect this, whilst objectives to maintain genetic diversity are considered at the national level.

Relevant Countryside Stewardship options

GS6 Maintenance of species-rich grassland

GS7 Restoration towards species-rich grassland

GS8 Creation of species-rich grassland

GS13 Management of grassland for target features

SP9 Threatened species supplement

Case Study

Northern Brown Argus Project
This project is led by Butterfly Conservation and seeks to improve the survival prospects of the northern brown argus in north-east England through a programme of vegetation management.

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Ring ouzel
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Ring ouzel *Turdus torquatus* L.

Climate Change Sensitivity:	HIGH	Ability to Manage:	MEDIUM
Non climatic threats:	MEDIUM	Vulnerability:	HIGH

Summary

The ring ouzel is a scarce breeding bird of the UK uplands which has probably been in decline here for at least one hundred years, with breeding atlases showing a reduction in range of 44% between 1972 and 2011, and UK breeding surveys indicating a 29% decline in numbers between 1999 and 2012 (Sharrock 1976; Gibbons *et al* 1993; Balmer *et al* 2013; Wotton *et al* 2016). Reasons for these declines are not well understood, although research has shown that poor first year survival may be one of the key factors.

Their reliance on upland habitats, and long-term declines in lowland parts of the UK, suggests that ouzels may be vulnerable to climate change, and this has also been suggested elsewhere in Europe. Habitat preferences have been well studied in the UK and trial management is underway in an attempt to determine if populations can be increased through habitat manipulation. Hopefully, the results will help to inform methods of increasing the resilience of this species to climate change through habitat creation and maintenance.

Description

The ring ouzel is a medium-sized thrush, very similar to but slightly smaller and less stocky than a blackbird, and with slightly longer wings and a distinctive white-cream breast band or gorget in adults. Unlike blackbirds, ouzels have silvery panels in the wings and silver-grey edges to the lower body feathers, often giving them a scaly appearance, which fades with time following the annual moult. Compared to blackbirds, they are generally shy and retiring, often restless, and have a harsh 'tacking' call and a plaintive, tri-syllabic, fluted song (Cramp 1988; Clement & Hathway 2000).

Ecology and distribution

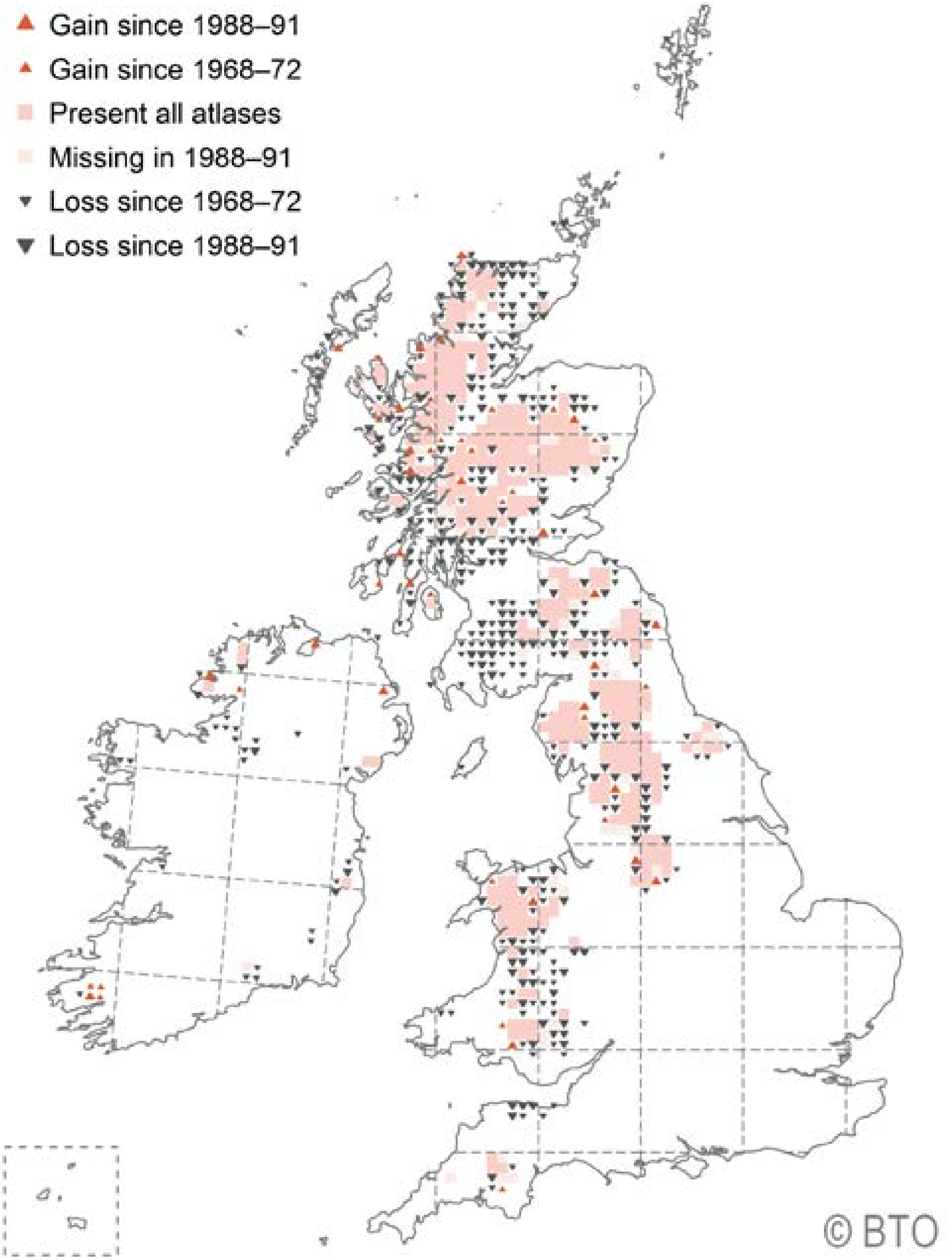
Ring ouzels generally arrive back in the UK from their Iberian and north African wintering quarters from mid-March onwards. They breed on open heather moorland and mountainsides, especially those with crags, scattered rocks, trees and shrubs. Nests are built on or under rocky ledges or banks in steep valleys and ravines, or on craggy hillsides, and are often overhung by heather. Very occasionally they nest in small trees, bushes and bracken. This contrasts with most of their European range, where they nest almost exclusively in trees (Flegg & Glue 1975; Cramp 1988).

During the breeding season, diet consists of a range of invertebrates, especially earthworms and beetles, with some leatherjackets, spiders, sawflies etc. These are usually obtained on the ground, and birds feeding young can fly several hundred metres to earthworm-rich pastures, where they will forage in company with birds from nearby territories. In late summer and on autumn passage, the berries of bilberry, crowberry, rowan, hawthorn and juniper are important. On passage, ouzels can be seen in lowland, especially coastal, locations. Groups of up to a dozen can often be seen moving through the hills in autumn, feeding on berries as they go. Most breeding ouzels leave the UK by mid-October, but some may linger, and Fennoscandian migrants continue on into November and December. In some years, a few individuals overwinter in the UK, but most spend the winter in the juniper scrub belt of the High Atlas Mountains of Morocco and Algeria (Cramp 1988; Appleyard 1994; Burfield 2002; Rollie 2007).

On migration, ring ouzels can be seen anywhere in the UK, but breeding is largely restricted to heathery upland areas above 250 m, exceptionally down to sea level in suitable habitat in northern Scotland. In 2012, the UK breeding population was estimated to be 5,332 pairs, with the bulk of these being in the Scottish Highlands and the Pennines, with smaller populations in Wales, southern Scotland, Lake District, North York Moors and Dartmoor, and a scattering of pairs on some of the inner Western and Argyll Isles.

Declines in breeding range have occurred throughout the UK, but between 1972 and 1991 were most pronounced in southwest England, Wales and Northern Ireland. Between 1991 and 2011, they ceased to breed in Northern Ireland, Galloway, Shropshire and Exmoor, while the small population on Dartmoor has declined by two thirds since the 1990s and is now very vulnerable (Jones 1996; Wotton *et al* 2016).

Historic changes in the distribution of the ring ouzel
(reproduced with permission of the BTO, from Balmer *et al* 2013)



Confidence in climate change impacts[34]

Distribution change: **HIGH CONFIDENCE** Mechanism: **LOW CONFIDENCE**

The Climatic Atlas of European Breeding Birds (Huntley *et al* 2007) predicts that, as a result of the projected increase in global temperatures, the shift in the simulated climate space for ring ouzel could be significant and might exclude England and Wales. While these simulations do not predict actual future range, they do show where suitable climate conditions are likely to be present and thereby indicate the potential range as a result of unameliorated climate change (Huntley *et al* 2007).

Given the restricted upland breeding distribution of ring ouzel and the long-term declines from lowland parts of the UK, climate change has often been mentioned as a possible cause, though often with little or no discussion of the possible mechanisms involved (Williamson 1975; Durman 1978; Poxton 1986; Cramp 1988). Burfield (2002) suggested that warmer conditions may allow blackbirds or other thrushes to expand their range into the uplands, increasing competition with ouzels, and this has also been mentioned by others (Parslow 1973; Sharrock 1976; Durman 1978). However, he found no evidence of occupancy by other thrushes of the many abandoned ring ouzel territories in the Moorfoot Hills (Borders) between 1998-2000, in his comparative study of the declining population there and the stable population at Glen Esk in Tayside.

Buchanan *et al* (2003) undertook the first objective study of the proposed causes of population declines through a correlative analysis of environmental, habitat and management variables potentially involved in ring ouzel declines between 1988-1991 and 1999. One of the key findings was that declines were more likely on flatter ground, and outwith an altitude range of 350-750m (i.e. above and below the core breeding altitudinal range of the species). In addition, between the periods 1952-85 and 1998-2000 breeding sites in the declining Moorfoot's population were more likely to have remained occupied if they were at higher altitude and had good heather cover (Sim *et al* 2007).

The growing interest in the potential impacts of climate change on upland species, prompted Beale *et al* (2006) to model the effect of temperature and rainfall on the breeding success and territory occupancy of ring ouzels in northern Britain. They used data from a range of study areas, including the Moorfoot Hills, where there was a long-term decline in ouzel abundance.

A link was found between change in territory occupancy and UK rainfall and temperature in late summer of the preceding year, and to rainfall in the wintering area two years previously. High UK temperature in late summer and intermediate late summer rainfall in the previous year, and high spring rainfall in Morocco (juniper flowering period) two years previously all had negative impacts on subsequent territory occupancy.

34 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

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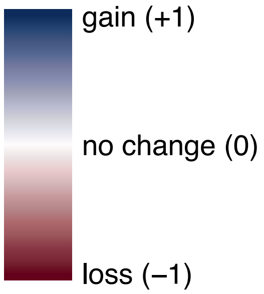
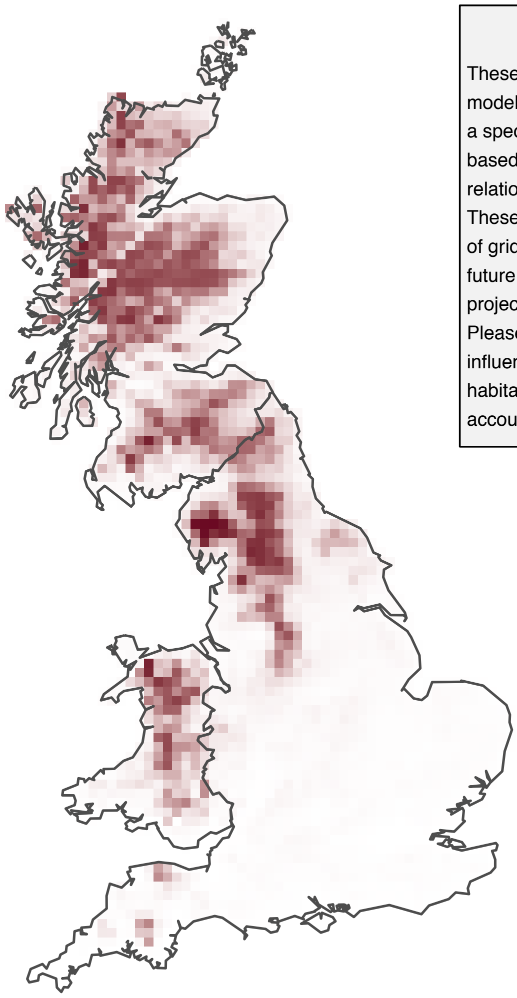
In recent decades there has been a significant increase in British summer temperatures and a significant decrease in summer rainfall, and the modelling suggested that these changes could underlie the declines in British ring ouzels (Beale *et al* 2006). This could affect both foraging adults and fledged young through reducing invertebrate food abundance, particularly earthworms, and/or through impacts on the fruiting period and abundance of billberry *Vaccinium myrtilis* and crowberry *Empetrum nigrum*. In an investigation of habitat preferences by juvenile ring ouzels in relation to seasonal variations in foraging conditions, no evidence was found that juveniles switched to berries due to a decline in earthworm abundance, nor that warmer, late summers were leading to a drying out of soils and reducing earthworm biomass (Sim *et al* 2013). However, the study was undertaken over only two years (one very wet) and on a population which had significantly declined over the previous decade (Sim *et al* 2013). For these reasons further work on this topic is needed.

Potential climate change impacts on ring ouzels have also been suggested in Switzerland, where models of climate change and habitat variables predict that there will be a decline of suitable habitat of as much as 20% and that median breeding ring ouzel range will be up to 440 m higher by 2070, contrasting with an increase in habitat at higher altitudes for blackbird (Busshe *et al* 2008; Satter *et al* 2016).

Projected change in potential distribution of ring ouzel in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015).



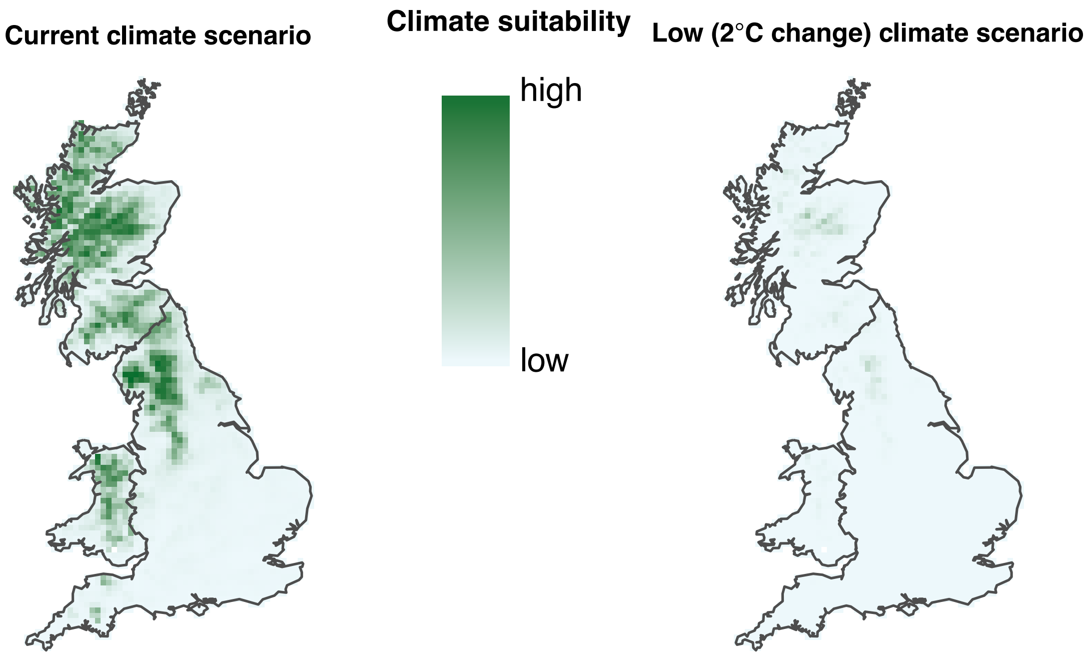


Climate suitability

These maps are created using statistical models which describe the probability that a species will be found in a 10 km grid square, based on its current distribution and its relationship to a number of climatic variables. These can be used to model the suitability of grid squares for a species under possible future climates when climate change projections are taken into account. Please note that other variables that influence species distributions, such as habitat and land–use change, are not accounted for in the modelling process.

Confidence of change

An assessment of the available data and other factors, as part of Natural England's Research Report NECR175, suggests that our confidence in this projection is very high. N.B. many confidence assessments are rated as low because there is a lack of published information on the likely influence of climate on the species concerned.



Created by:	University of York	Created for:	Natural England	Created on:	August 17 2016

Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

The main aim of adaptation for the ring ouzel within England is to secure healthy populations within their current range. It may however be most effective to focus on areas likely to remain climatically suitable for the species, largely in the north of the country. This includes ensuring optimum management of key reserves and protected sites that currently support breeding ring ouzels, and improving the condition of other sites in parts of the country that are likely to remain climatically suitable.

Currently, it is unclear what actions need to be taken as we are unsure about the relative importance of climate change, loss of suitable habitat/food sources or anthropogenic factors in driving population change, and if these factors are acting on the breeding, migration or wintering grounds. However, as a result of recent research, we do know enough about ring ouzel breeding ecology and habitat requirements to begin to at least make their existing and potential breeding areas more attractive to them and thereby, hopefully, more resilient to climate change.

Research has highlighted the importance of heather and short grass mosaics, together with the availability nearby of berries such as bilberry and crowberry (Burfield 2002; Buchanan *et al* 2003; Sim *et al* 2013). We also know that conifer afforestation within or near key breeding areas is detrimental to ouzels, probably for a variety of reasons but certainly including direct habitat loss, changes in grazing regimes and increased numbers of predators (Buchanan *et al* 2003; Smith and Green 2000).

Potential adaptation actions for the ring ouzel include:

- Protect existing breeding areas from overgrazing, over-burning, or inappropriate woodland planting.
- Create and maintain suitable heather and grass mosaics through appropriate grazing and burning regimes and controlling excessive bracken encroachment.
- Create invertebrate-rich areas through appropriate management, including drain-blocking.
- Consider controlling predators where predation is known to be significant.
- Identify topographically suitable but vacant areas within the existing breeding range and manage them with a view to attracting ring ouzels, where this is thought feasible.
- Manage and maintain habitat (e.g. areas of short grass mixed with berry-bearing shrubs) at known stop-off points on migration routes.
- Investigate migration movements and wintering areas with a view to positively influencing the numbers of ouzels returning to the UK annually, thereby increasing population resilience.

To support these actions, it is also important to:

- Establish a robust monitoring regime to determine population trends and the effectiveness of interventions.
- Monitor population trends. Minimal numbers of 1 km squares in UK and England are currently covered by the Breeding Bird Survey to enable annual population estimates; more monitoring, particularly in Scotland is required.

Relevant Countryside Stewardship options

UP1 Enclosed rough grazing

UP2 Management of rough grazing for birds

UP3 Management of moorland

UP6 Upland livestock exclusion supplement

Case Studies

The RSPB, with support from Natural England, is currently undertaking trial management for ring ouzels on its reserves at Geltsdale in Cumbria and Dove Stone in the Peak District. This project began in 2014, and initial results are promising. At Geltsdale, breeding numbers in the valley being managed increased from no pairs in 2014-15, to 1 pair in 2016 and 2 pairs in 2017. Here the management intervention was to introduce grazing by Exmoor ponies in order to reduce excessive bracken cover and create short grass sward for foraging ouzels. At Dove Stone, breeding numbers in the valley being managed increased from 2 pairs in 2014-15, to 3 pairs in 2016 and 4 pairs in 2017. Here, it was thought that overgrazing in the past had reduced the extent of dwarf-shrub cover used by ouzels for nesting. Thus, a fence was erected to exclude sheep grazing from the upper slopes, in order to encourage the growth of dwarf-shrub cover. Meanwhile, breeding numbers in nearby 'control' valleys, where no management work is being carried out, decreased from 3 to 1 pairs at Geltsdale, and from 8 to 2 pairs at Dove Stone. These initial results are promising, but more time is needed to determine if these apparent changes are sustained in the longer term. The project is planned to continue in the future, with monitoring taking place at 3-year intervals from 2020.

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Silver spotted Skipper *Hesperia comma*
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Silver spotted skipper *Hesperia comma*

Climate Change Sensitivity:	POTENTIAL BENEFIT	Ability to Manage:	HIGH
Non climatic threats:	MEDIUM	Vulnerability:	LOW

Summary

The silver spotted skipper is a warmth loving species that is benefiting from climate change. Historic declines resulting from the loss or degradation of habitat are being reversed, in part due to a climate change driven expansion. Adaptation can best focus on facilitating the continued expansion of the species by ensuring effective ecological networks are in place. This should include ensuring the optimum management of existing grassland and the creation of new habitat in areas where natural colonisation is inhibited.

Description

The silver spotted skipper is a small butterfly with orange upper wings, with brown margins and pale orange spots. Males are distinguished from females by a thick black line running through the centre of the forewing. They are easily distinguished from similar skipper species by the numerous silvery spots on the underside of the hindwings.

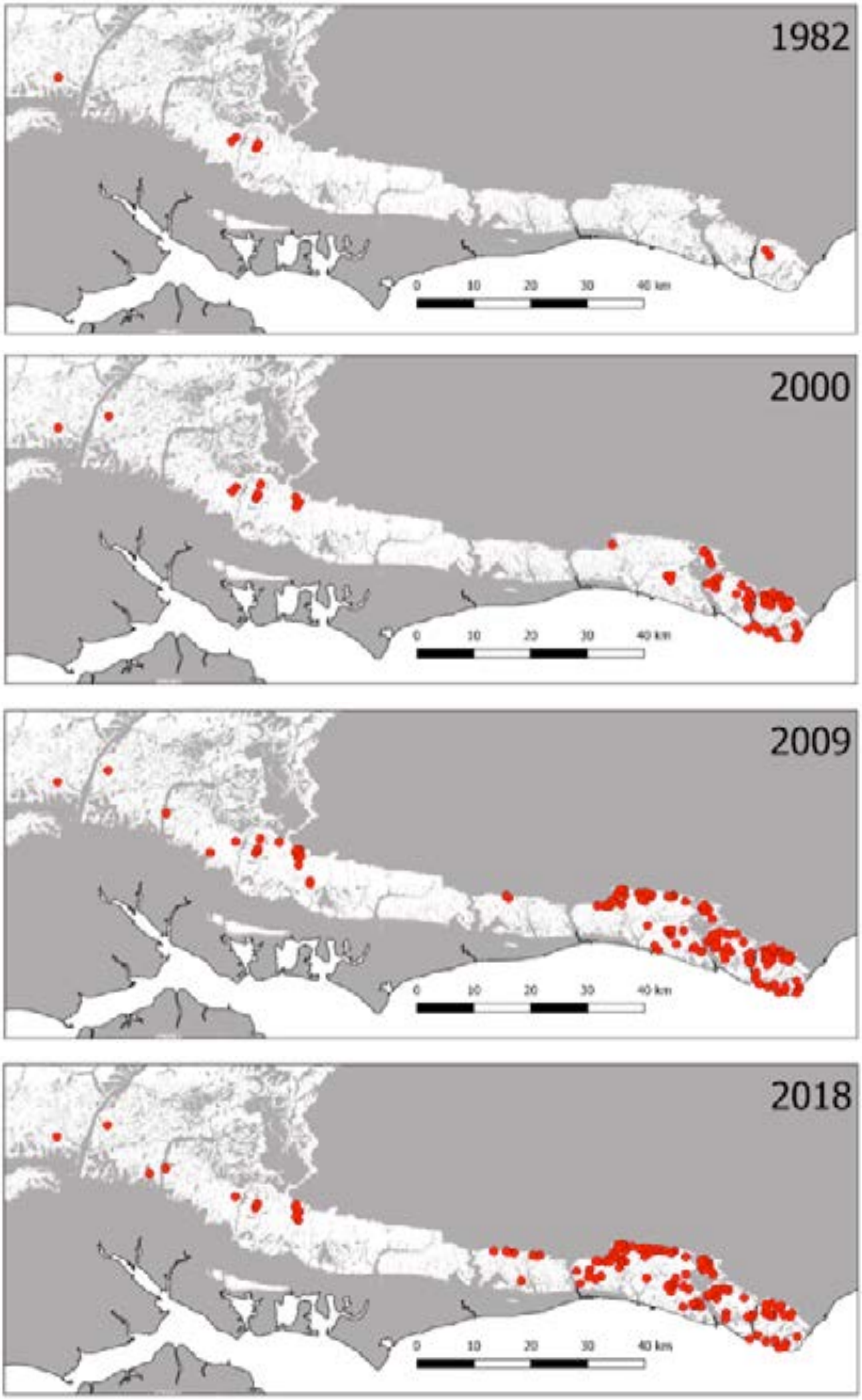
Ecology and distribution

The silver spotted skipper is a warmth loving species that reaches the northern limit of its range in southern England, where it is restricted to unimproved chalk grassland with short turf. It is one of the last butterflies to emerge, appearing in late July or early August, and remains on the wing until early September. There is one generation each year. It lays its eggs on sheep's fescue *Festuca ovina*. Eggs hatch the following March, and caterpillars feed exclusively on the leaves of sheep's fescue. Females are highly selective about the sites on which they lay eggs, selecting hot micro-climates. Historically, this meant the only suitable oviposition choices were tufts of sheep's fescue less than 10 cm tall adjacent to patches of bare ground such as rabbit scrapes or animal tracks, on south facing slopes (Thomas *et al* 1986). More recently, warmer summers have led to sheep's fescue occurring in taller swards, a reduction in the requirement for bare ground, and the use of a wider range of topography, including north facing slopes, becoming suitable (Davies *et al* 2006).

Historically, the silver spotted skipper was recorded on chalk soils over much of southern Britain and as far north as the Yorkshire Wolds, but in the second half of the 20th century it underwent a dramatic decline (Thomas *et al* 1986). The main cause of this decline was the loss of short-turfed unimproved grassland, largely due to agricultural intensification and the abandonment of extensive grazing, and the decline in rabbit populations due to myxomatosis.

Conservation intervention, the recovery of rabbit populations, and climate change have reversed this decline, and by 2000 the species had undergone a partial re-expansion in England (Davies *et al* 2005), with more than three times the number of populations present than in 1982 (Lawson *et al* 2013).

Figure 1: Changes in the distribution of silver spotted skipper in the South Downs, 1982 to 2018. White shading represents chalk geology, red circles represent locations of populations (Bennie 2020).



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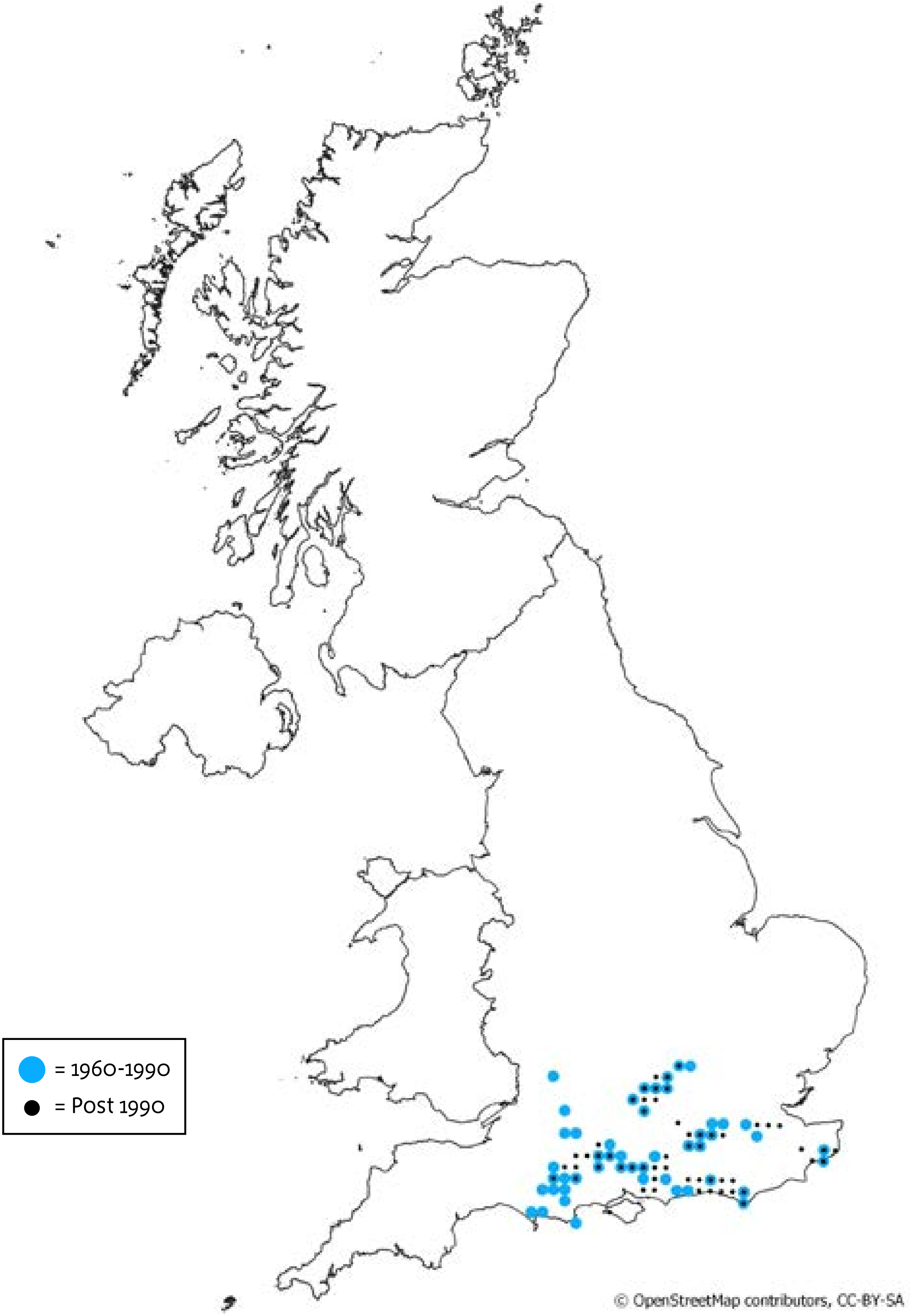
Warmer summers have reduced the silver spotted skipper's need for bare ground and very short turf on south facing slopes, and have allowed it to breed in taller swards and on north-facing slopes, increasing the area of potentially suitable habitat. However, many populations remain small and the limited dispersal ability of the butterfly is restricting its expansion (Wilson, Davies & Thomas 2010), with sites over 2 km from existing sites less likely to be colonised (Lawson *et al* 2013). The species is still vulnerable to localised extinction, with populations at the species' northern margin and on north-facing slopes most likely to suffer extinction (Lawson *et al* 2012). The more recent decline in rabbit populations with the associated impact on sward conditions and the extent of bare ground has arrested the recent expansion of the silver spotted skipper and led to local losses, especially at the western margin of its current range (N.Bourn pers. comm.).The species has been shown to colonise protected areas more readily than non-designated grassland (Lawson *et al* 2014), highlighting the role of conservation management in promoting its expansion.

Butterfly Conservation's presence records for silver spotted skipper over 2 timeslices, 1960-1990 and post 1990, are shown on the map below (10 km grid scale).

Presence of silver spotted skipper records, 10km[2].
Source: Butterfly Conservation: Butterflies for the New Millennium.



Confidence in climate change impacts[35]

Distribution change: **HIGH CONFIDENCE** Mechanism: **HIGH CONFIDENCE**

The life-cycle of the silver spotted skipper is dependent on the availability of a hot micro-climate, with egg laying being temperature-dependent (Davies *et al* 2006). Historically, the availability of host plants in sufficiently hot micro-climates was restricted to sparse short swards on south facing slopes, in close proximity to bare ground. This made the butterfly vulnerable to changes in sward height, as demonstrated by its previous decline following reductions in grazing by livestock and rabbits.

Warmer summers have increased the availability of suitable micro-climates. Females have been shown to alter their choice of egg-laying site in relation to the ambient temperature, utilising a greater range of sward conditions and topography within existing sites (Davies *et al* 2006). This has increased the area available to the butterfly within its current range, and facilitated its northward expansion (Bennie *et al* 2013, 2020). These benefits might be offset to a degree by the decline of bare ground, due to milder winters leading to an increased length of the growing season.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

Climate change adaptation for this species in England means facilitating its positive response to increasing temperatures. The management of existing sites can ensure suitable swards for the species. In most cases, the provision of short turf to improve the resilience of populations to cooler summers will remain important, however adults have been shown to become heat stressed at high ambient temperatures (Davies *et al* 2006), so the provision of suitable shading via patches of longer turf or scrub is likely to be beneficial, especially on south facing slopes.

- Sward management can be adjusted to reflect the changing oviposition preferences of the butterfly and promote greater variation in sward height, ideally achieved through cattle or mixed grazing.
- To ensure suitable sward conditions stocking levels may need adjustment to compensate for changes in rabbit populations.
- The provision of isolated scrub to provide shading may be encouraged on south facing sites, especially those prone to drought.
- To increase population size and number of colonies by natural processes, habitat restoration and creation should be targeted to expanding existing sites, and ensuring that suitable habitats are separated by less than 2km.
- Site boundaries and conservation objectives should be reviewed and, where necessary, adjusted to reflect the changing patterns of use by the butterfly and projected changes to its distribution.
- Translocation to suitable sites unlikely to be colonised naturally could be considered, although action to promote the natural expansion of the species should be the priority.

35 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Relevant Countryside Stewardship options

GS6 Management of species-rich grassland

GS7 Restoration towards species-rich grassland

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Small red damselfly pair *Ceriagrion tenellum*
© Natural England/Des Sussex

Small red damselfly
Ceriagrion tenellum (de Villers).

Climate Change Sensitivity:	HIGH	Ability to Manage:	MEDIUM
Non climatic threats:	HIGH	Vulnerability:	HIGH

Summary

The small red damselfly has a restricted distribution, and is found on heaths and wetlands in Southern and South West England. It has poor dispersal abilities and, unlike many other species at the northern edges of their range, the small red damselfly is projected to suffer rather than benefit from projected climate warming. This in part is due to its association with marsh St John's wort, which shares a similar distribution and is also considered to be vulnerable to climate change. Its high level of preference for watercourses associated with small bogs and slow flowing runnels makes it highly susceptible to changes in patterns of rainfall, abstraction or drainage.

Ensuring hydrological conditions are maintained in existing sites, and creating or restoring suitable habitat in locations close to these sites, are likely to be the most effective adaptation actions.

Description

The small red damselfly is one of our smallest damselflies and it is one of only two red damselfly species in the UK. The male has an all red abdomen. The females exist in several colour forms, with varying amounts of red and black on the abdomen. Both sexes have a bronze-black thorax and a red pterostigma[36].

Ecology and distribution

In England, this species is at the extreme north-western edge of its range. It has good populations in south west England and around the New Forest. Cornwall is a particular stronghold. Its preferred breeding habitat is narrow, shallow streams and runnels within wet heaths and valley mires where the pH varies between 5.5 and 8.5 (Askew 1988; Strange *et al* 2007).

It is found in small, sunny, unshaded, shallow waters with low flows, such as acid bogs or pools with lots of plant life (Strange *et al* 2007). The larvae need high water temperatures to develop, and are susceptible to competition from other species. It is a relatively weak flier, with most movement restricted to the centre of colonies (Parr & Parr 1979).

Eggs are laid in submerged and emergent plants and hatch after about a month. The larvae develop over two years. Emergence occurs over a relatively long period, which is typical of summer species of Odonata due to the over-wintering larvae being at different stages. The flight period runs from early June through to late August.

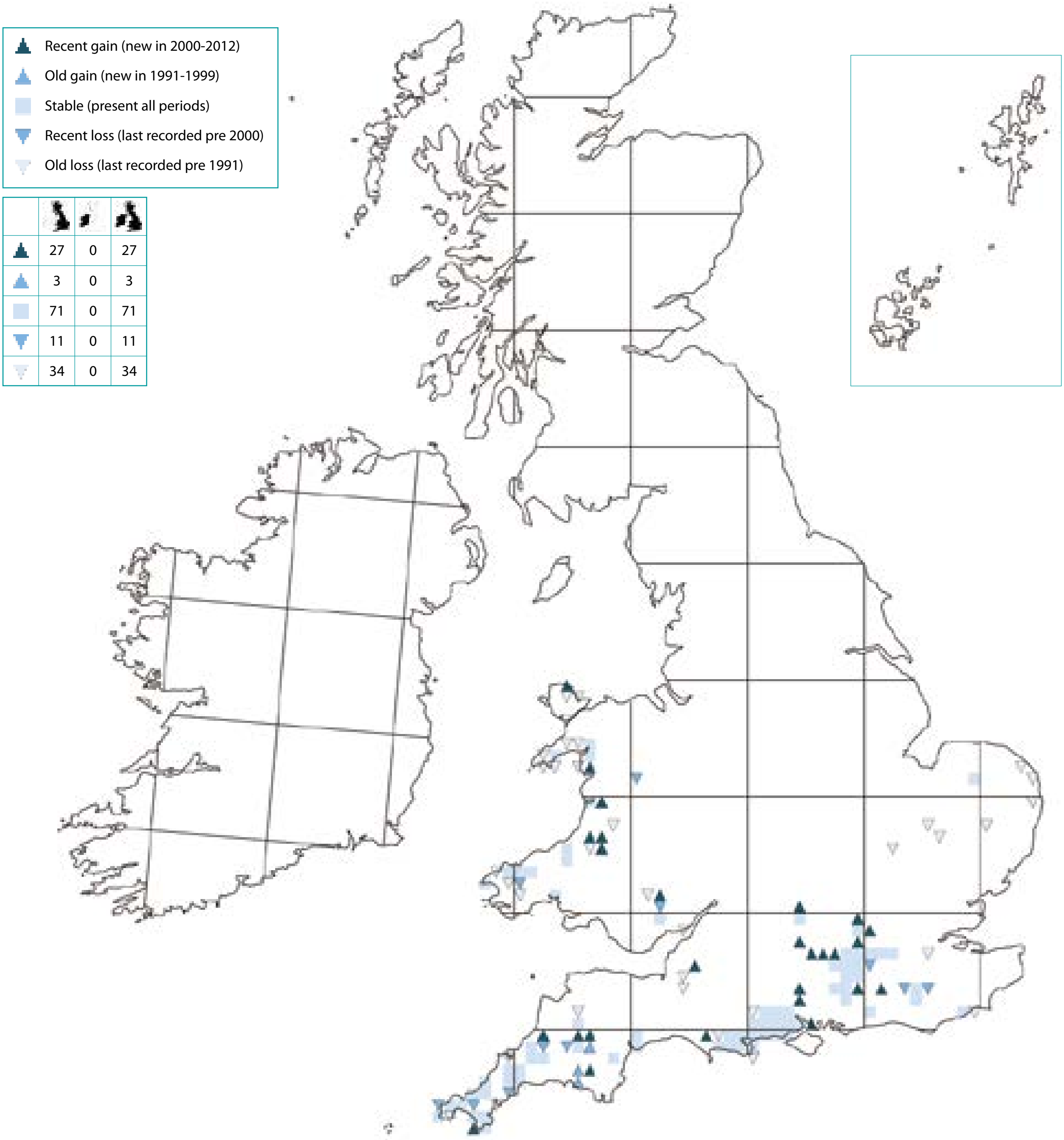
Although it is relatively widespread across areas where it is found, within this there are areas with no colonisation, suggesting a high level of specificity in its habitat requirements (Strange *et al* 2007; Hassall & Thompson 2010). Key factors associated with the selection of oviposition sites are thought to be the extreme selectivity of the flying population for boggy stream areas with little open water, and the presence of the water plant marsh St John's wort *Hypericum elodes*. It is probable that specific habitat requirements are the primary reason for the species' very limited distribution (Buchwald 1992).

It has suffered historic declines across its range as a result of wetland drainage and the fragmentation of heathland through agricultural improvement and afforestation (Brooks 2001).

The British Dragonfly Society records for small red damselfly are shown on the map below (10km grid scale).

36 A thickened or coloured cell in the outer wings of insects which stands out from other cells. They are particularly noticeable in dragonflies and damselflies.

Presence of small red damselfly records, 10km².



Recent gain	27	0	27
Old gain	3	0	3
Stable	71	0	71
Recent loss	11	0	11
Old loss	34	0	34

Map © Natural Environment Research Council and British Dragonfly Society (2014).

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Confidence in climate change impacts[37]

Distribution change: **LOW CONFIDENCE** Mechanism: **LOW CONFIDENCE**

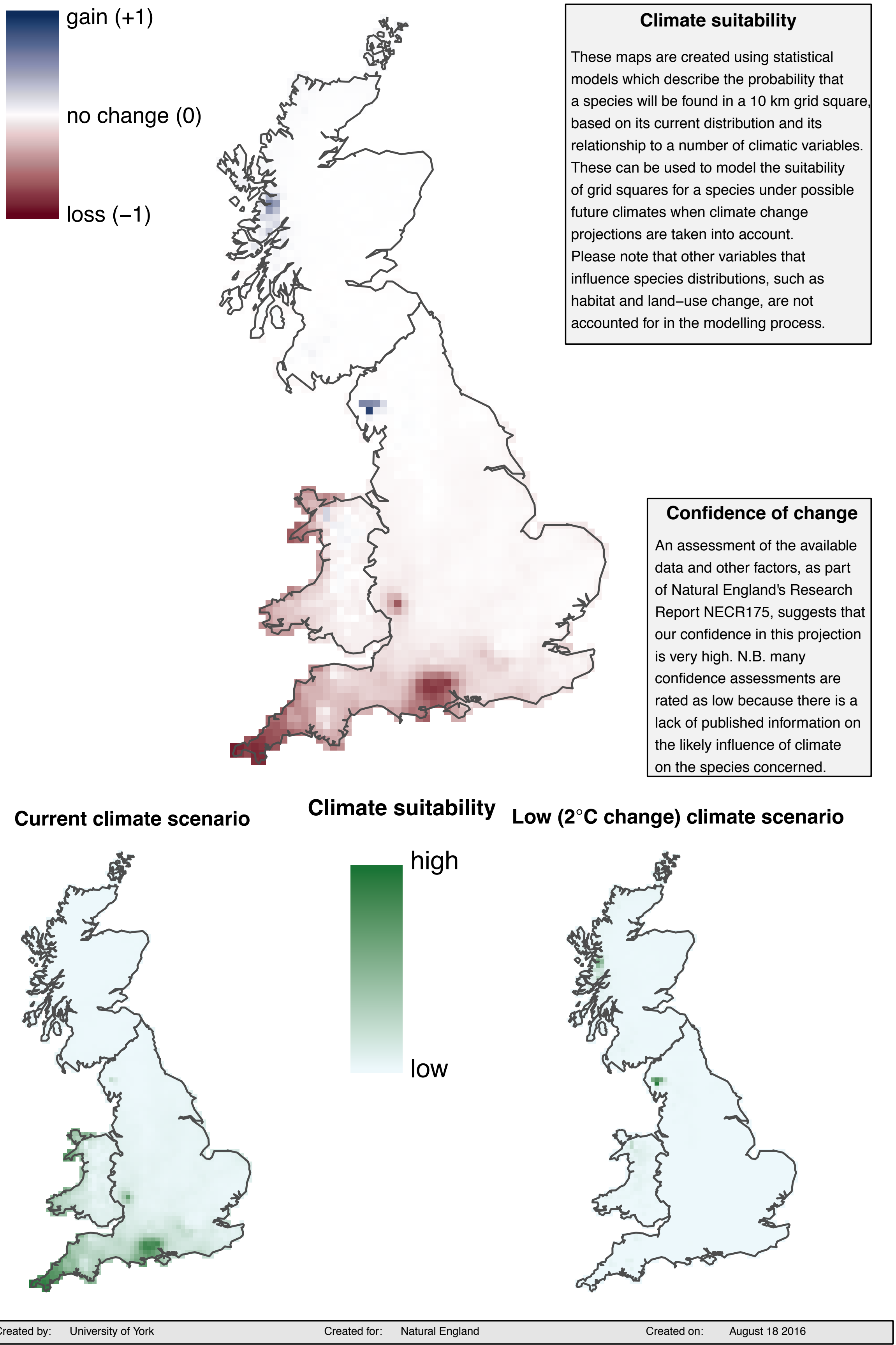
The small red damselfly is largely a Mediterranean species and is therefore well adapted to warm conditions. However, it has been shown to be highly sensitive to summer drought (Parr & Parr 1979; Chelmick 1980). In common with many other invertebrate species, the timing of its summer emergence is advancing in a manner consistent with warming (De Bruyn 2012), at a rate of over 2 days per year in Europe since 1990. Its specific habitat requirements have been identified as being the reason why its distribution is not responding positively to a warming climate (Hassall & Thompson 2010). The close association with marsh St John's wort increases the vulnerability of the damselfly as this plant is also considered to be vulnerable to climate change driven changes in rainfall (Carta 2014).

Because of its specific habitat requirements, projected changes in rainfall patterns present a clear threat to the species. An increase in the frequency of high intensity rainfall events is likely to lead to more flooding and erosion, and changes to the seasonal patterns of rainfall will lead to greater fluctuations in water levels and flow. Both will have an adverse impact on the quality of habitat in the water courses the species currently occupies.

The small red damselfly has been shown to be susceptible to competition from other colonising Odonata species (Walther, Burga & Edwards 2001), so any climate driven changes in the populations of other species could have a detrimental impact on the small red.

37 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Projected change in potential distribution of small red damselfly in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015).



Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

Understanding the specific habitat requirements of the small red damselfly is important for identifying site specific vulnerability to climate change and appropriate actions to mediate these impacts. Possible options include:

- Ensure optimum management of existing sites through the appropriate management of water levels and water quality to preserve hydrological conditions, and by controlling scrub to encourage vegetation, particularly marsh St John's wort.
- Maintain a range of suitable habitats by restoring or creating new sites between existing locations, to re-connect populations and encourage interactions between them.
- Artificial re-establishment on suitable sites distant from existing populations should be considered due to the relatively poor dispersal ability of adults and its specific habitat requirements, targeting places where suitable climatic conditions are most likely to persist.
- Establish monitoring programmes to determine population trends and the effectiveness of interventions.
- If it is suspected that climate change is responsible for losses, undertake research to identify the mechanisms driving these losses, including the impact of other species of Odonata on the viability of small red populations.

Relevant Countryside Stewardship options

WT10 Management of lowland raised bog

FM2 Major preparatory works for Priority Habitats (creation and restoration) and Priority Species.

Case Study

Eelmoor Marsh

Eelmoor Marsh, near Farnborough, Hampshire is a 79 ha fragment of the formerly extensive Cove Common, consisting of a complex of wet and dry heath, species rich grassland, mire, and woodland. The Common underwent rapid change throughout the 19th and 20th Centuries, with the cessation of traditional land use, the planting of a pine plantation, and extensive drainage. Since 1995, the land owners have sought to restore neglected habitats by introducing year round, low intensity grazing, removing invasive trees, and modifying the hydrology of the site. Diversification of aquatic habitats in particular has benefited dragonflies and damselflies, and the site is now an important place for the small red damselfly.

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Tree lungwort
© Tim Wilkins

Tree Lungwort *Lobaria pulmonaria* (L.) Hoffm.

Climate Change Sensitivity:	HIGH	Ability to Manage:	MEDIUM
Non climatic threats:	HIGH	Vulnerability:	HIGH

Summary

This charismatic, leafy lichen is special to Britain in that much of its European population occurs here. In England, tree lungwort is closely associated with parklands and ancient wood pasture, including 'temperate rainforest' to the north and west along the Atlantic seaboard. As an epiphyte, it grows on a wide range of broadleaf trees, but in England chiefly occurs on oak and ash. Historically, it has suffered marked declines due to sulphur dioxide pollution and 'acid rain', loss of ancient/veteran trees, and changes in woodland management. Today, it is an uncommon species in England and shows little sign of re-colonising areas from which it was lost. Tree Lungwort is possibly the most researched lichen species globally, and there is strong evidence of its high sensitivity to air quality and climate. Many colonies in England are small, isolated from one another, and, those in less oceanic areas, are already in climatically sub-optimal conditions. Together these factors increase the risk of local extinction and range contraction, especially under a changing climate.

Description

Tree lungwort is a large foliose (leafy) lichen that can form spectacular cascades down tree trunks and along branches. Its appearance changes depending on whether it is wet or dry, being khaki to green-grey when dry and bright green when wet (Dobson 2011). Individuals can exceed 30cm in width, and when fertile its spore-producing fruitbodies are easily visible as orange to red-brown discs up to 4mm diameter (Smith *et al* 2009). The upper surface of the lichen has a distinctive network of ridges and depressions that are lung-like in appearance. The ridges and lobe margins are often lined with minute vegetative propagules. In contrast, the lower surface is finely tomentose, brown, and covered in pale blister-like swellings. The morphology is variable, according to substrate and climatic conditions as well as to size and age of the thallus (Wolseley & James 2000).

As a symbiotic organism, this lichen is chiefly composed of a fungus with a thin layer of photosynthetic green algae (*Dictyochloropsis reticulata* in this case) beneath its surface, but it can also develop tiny wart-like structures containing cyanobacteria (*Nostoc*) that are not only photosynthetic but can fix nitrogen from the air. Tree lungwort individuals (ramets) grow seasonally during the wetter months (Muir *et al* 1997) and have an expected lifespan of about 40 years, although tree colonies can persist until the tree dies (Scheidegger, Frey & Walser 1998; Öckinger & Nilsson 2010). Under optimal conditions, for example in the highly oceanic climate of west Scotland, the species is capable of comparatively rapid growth and colonisation (Eaton & Ellis 2014).

Tree lungwort is host to many lichenicolous fungi (fungi that grow on lichens). Of these, some appear to be specific to L. *pulmonaria* (Etayo & Diederich 1996; Coppins & Coppins 2005).

Ecology and distribution

This species is scarce and has declined in England. It was once reported from all English counties except Huntingdonshire, Middlesex, Norfolk and Northamptonshire (Hawksworth, Rose & Coppins 1973), but today is present in less than 30% of English counties (including the above) (Greenaway & Wolseley, in press).

Although its current GB threat status is Least Concern (Woods & Coppins 2012), this is due to large healthy populations in the west of Scotland. In Wales, the species is red-listed as Vulnerable (Woods 2010). In central and northern Europe there have been substantial declines during the twentieth century and this species is considered threatened in many European lowland countries (Rose 1988). Consequently, in Britain it is listed as an International Responsibility species (Woods & Coppins 2012) despite the species being quite widespread globally (Widmer *et al* 2012). This species is also prohibited from sale under Schedule 8 of the Wildlife & Countryside Act (1981, as amended).

Tree lungwort prefers cool, wet climates and is considered a strong climate indicator (Will-Wolf *et al* 2015). In sub-oceanic areas of Central Europe it typically occupies the montane zone but is otherwise limited to more oceanic areas with high rainfall (Rose 1988; Wirth 2010). A fundamental requirement for this species is clean air. It is highly sensitive to air pollution, both acidic (i.e. sulphur dioxide), and fertilising (i.e. nitrogenous) compounds (e.g. Will-Wolf *et al* 2015).

In England, its primary habitats are ancient pasture woodlands and old parkland, including, under a much more oceanic climate, grazed upland oakwoods in Cumbria. Because of the strong association with old-growth woodland, tree lungwort is considered as an 'old forest indicator' species in Britain, Europe and Canada (Rose 1976; Andersson & Appelqvist 1987; Coppins & Coppins 2002; Campbell & Fredeen 2004).

In common with other lichens, this species will only grow on particular substrates, showing a preference for slightly acidic bark (Looney & James 1990; Wirth 2010). In England, its most common hosts in decreasing order of frequency are: oak, ash, sycamore, beech and willow (Greenaway & Wolseley, in press). Less frequently, it grows on other trees and shrubs, heather and even mossy rocks. Trees with a naturally high bark pH have a buffering effect to acidifying pollution, providing refugia for *Lobaria* species (Wolseley & James 2000). Favoured substrates include moss mats on lower trunks or directly on the bark in more exposed parts of the tree. The presence of bryophytes (at low to intermediate cover values) may facilitate tree lungwort colonisation (Jüriado, Leelia & Liira 2012; Eaton & Ellis 2014). Tree girth is also an important factor in less oceanic areas, with tree lungwort showing a preference for large diameter trunks, and restricted to trees over 100 years of age (Gauslaa 1985; Öckinger, Niklasson & Nilsson 2005; Edman, Eriksson & Villard 2008).

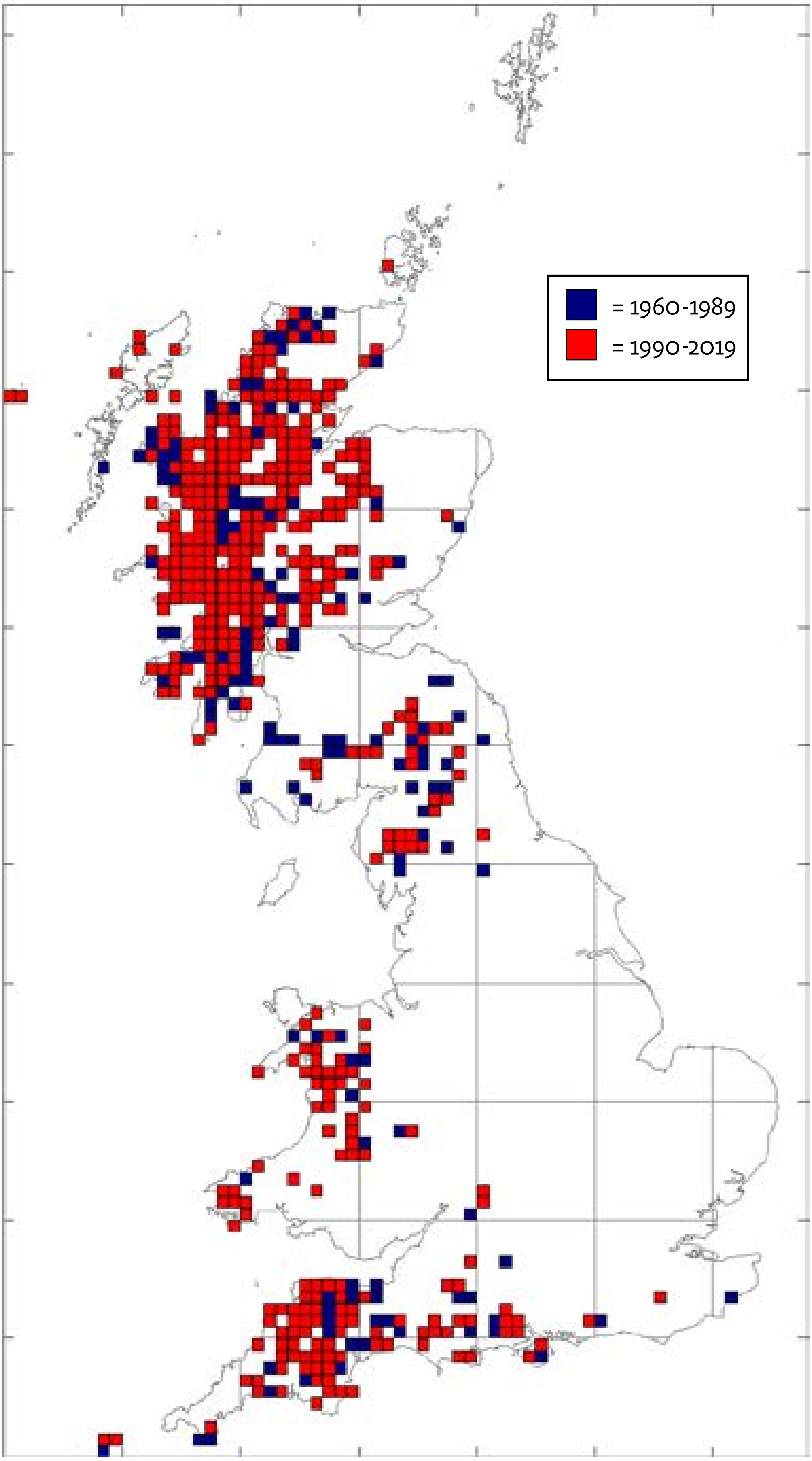
Tree lungwort needs moderate-high light levels to thrive but can be killed by exposure to direct sunlight (Gauslaa & Solhaug 1999, 2000). In semi-natural woodland these conditions are typically achieved through the collapse of post-mature trees and/or woodland grazing which suppresses tree regeneration and understorey vegetation. In managed woodland, glades and rides provide similar conditions and are good alternatives where they can be maintained (Sanderson 2012; Lamacraft *et al* 2016).

Aside from habitat loss and agricultural intensification (slurry and inorganic fertilisers), which are still relevant today, the main causes of past decline have been sulphur dioxide pollution (near population centres) and, more generally, 'acid rain' and Dutch Elm Disease (Hawksworth, Rose & Coppins 1973; Watson, Hawksworth & Rose 1988; Looney & James 1990). Historically, the species was collected from the wild for medicinal applications (Crawford 2015).

Today, the key non-climatic pressures are woodland neglect (understorey development and invasive non-native shrubs), habitat discontinuity (cohort gaps in tree populations), and air pollution caused by an increase in nitrogenous compounds from both agricultural sources and vehicle emissions (Wolseley & Lambley 2004; Mitchell *et al* 2005; Yemets, Solhaug & Gauslaa 2014; Greenaway & Wolseley, in press).

The British Lichen Society occurrence records for tree lungwort are shown on the map below (10km grid scale).

Known occurrence of tree lungwort, 10km². Map kindly supplied by the British Lichen Society.



Confidence in climate change impacts[38]

Distribution change: **HIGH CONFIDENCE** Mechanism: **MEDIUM CONFIDENCE**

Epiphytic lichen distributions are strongly influenced by macroclimate (van Herk, Aptroot & van Dobben 2002; Werth,Tømmervik & Elvebakk 2005; Aptroot & van Herk 2007). Lichens have no means of regulating their water content, which naturally finds equilibrium with the environment (Honegger 1998). As a result, they are rapidly affected by changes in humidity and rainfall, and more susceptible to desiccation than many other organisms, although they have complex adaptations to cope with this (Schofield *et al* 2003; Gauslaa *et al* 2006; Kranner *et al* 2008).

Tree lungwort is most at home in the wettest parts of Britain, the Atlantic woodland of the west coast. Any sustained changes to the precipitation patterns here would very likely impact on the range and abundance of the species. Oceanic species tend to have higher niche specificity in a drier climate (Werth, Tømmervik & Elvebakk 2005; Scheidegger & Werth 2009), hence populations to the east and south in Britain may already be drought stressed and less tolerant to rising temperatures. The 1989 drought has been attributed as one of the causal factors of *Lobaria* decline in SW England (Wolseley & James 2000). Higher temperatures, in combination with increased risk of sun-scorch, have been shown to be detrimental to tree lungwort (Gauslaa & Solhaug 2000, 2001). Nevertheless, the species may fare better than other *Lobaria* species in future, although current bioclimatic models appear insufficiently nuanced to make accurate predications (Nascimbene *et al* 2016; Ellis *et al* 2017; Eaton *et al* 2018).

In England, tree lungwort faces a number of constraints that could reduce its adaptive potential to climate change. For example, individuals are seldom fertile (lacking sexual spore-producing structures) and colonisation of new sites appears exceedingly slow (Rose 1993; Wolseley & James 2000; Greenaway & Wolseley, in press). In addition, this species has two self-incompatible mating types, reducing the chances of sex in fragmented populations (Singh *et al* 2012, 2015). Clonal reproduction is thus relatively more important, although it is estimated to take 35 years growth before thalli produce vegetative propagules (diaspores) (Scheidegger & Goward 2002). Moreover diaspore dispersal is short range, possibly limited to 15-30m from the parent (Walser 2004; Jüriado *et al* 2011). At a landscape scale, genetic analyses have shown that tree lungwort is (or was) capable of wider dispersal (Werth *et al* 2006, 2007; Otálora *et al* 2015). Nevertheless, small populations may be unsustainable, representing an extinction debt (Scheidegger, Frey & Walser 1998; Öckinger & Nilsson 2010).

Indirect impacts include threats to substrate trees. Increasing storminess, more frequent/severe droughts and flooding are likely to cause a rise in windthrow and canopy damage (Broadmeadow 2002). New and emerging tree pests and diseases are also likely to diminish native tree populations, e.g. ash dieback is expected to impact on tree lungwort (Edwards 2012).

Fertilisation from rising CO_2 levels is expected to have varying effects on vegetation but may increase canopy shading (a denser canopy and more prolonged due to earlier bud-break) in upland oak woods, which could threaten this species (Broadmeadow 2002; Körner 2003; Masters *et al* 2005). Similarly, the enhanced growth of understory vegetation, e.g. saplings, may further reduce light levels. Climbing plants such as ivy, which tend to shade out epiphytic lichens, are increasing, showing a competitive advantage from rising CO_2 levels (Zotz, Cueni & Körner 2006).

Please read this case study alongside the relevant habitat sheets.

38 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Adaptation options

The narrow ecological niche of this species in England, combined with its small, fragmented, infertile populations, makes this species especially vulnerable to environmental change. While uncertainties exist over how this lichen will respond to further climate change, a range of no/low regret measures can make populations more resilient. Adaptation at existing sites should focus on reducing known pressures and optimising habitat condition, but further measures are advisable to build populations to sustainable levels and help to regain its former range.

Further studies are needed to determine the likely impacts of climate change on this species and the *Lobarion* community in general, especially to trial and monitor adaptation techniques. Since this species can be slow to respond to more favourable conditions, a long view of habitat provision and management is needed, and population monitoring will be key to adapting management regimes.

Actions to promote resilience include:

- Optimise habitat conditions at existing sites. For example, maintain light levels through sufficient grazing and control of young ivy growth (Sanderson & Wolseley 2001; Lamacraft *et al* 2016). The exclusion of grazing animals from woodlands and/or non-intervention conservation policies that lead to a reduction in woodland grazing would very likely negatively impact on this species due to increased levels of shade. A more natural approach would be to restore large tracts of grazed woodland, creating a varied woodland structure with many open areas (Sanderson 2012).
- Maintain the structural diversity of tree stands and the availability of potential host trees (Jüriado *et al* 2011). Sustained conservation depends not only on old and large trees but also a wide range of tree sizes and ages (Kiebacher *et al* 2017).
- Restore former pasture woodland sites. Extend or link existing wood pasture/parkland sites to increase available habitat, including wider cohorts of trees to address age gaps.
- Encourage nitrogen mitigation where relevant to the site, such as through a Shared Nitrogen Action Plan (SNAP) (refer to the IPENS Atmospheric nitrogen theme plan for further details).
- Consider supplementing populations through conservation translocations, the creation of local reinforcement colonies, and site reintroductions within its former range (Scheidegger 1995; Scheidegger, Frey & Walser 1998; Gustafsson, Fedrowitz & Hazell 2013). If the species cannot keep pace with its climate envelope, consider introductions to sites beyond the known historical range. Follow the IUCN guidelines for reintroductions and other conservation translocations (IUCN/SSC 2013).

Actions to accommodate change include:

- Conserve a wider range of tree species (native and non-native) that are known to provide suitable substrate (Ellis *et al* 2014). For example, mature/post-mature sycamore provides an excellent substrate for this species.
- To address enhanced vegetation growth caused by elevated CO_2 levels and maintain light levels, increase grazing pressure if necessary, create additional glades or rides, and control (and monitor) ivy growth (Zotz, Cueni & Körner 2006; Coxson & Stevenson 2007).
- Where the loss of substrate trees is not compensated for by natural regeneration, a programme of tree planting (using a mix of species) may help to maintain continuity of epiphyte habitat. Priority should be given to known substrate trees (native and non-native) and, in relation to climate change, matching the tree species and provenance with the relevant site (Broadmeadow, Ray, & Samuel 2005).

Relevant Countryside Stewardship options

The most relevant Countryside Stewardship options for tree lungwort are listed below:

BE1: Protection of in-field trees on arable land

BE2: Protection of in-field trees on intensive grassland

BE6: Veteran tree surgery

PA2: Feasibility study

SB2: Scrub control - difficult sites

SB6: Rhododendron control

SP4: Control of invasive plant species supplement

SP6: Cattle grazing supplement

SP9: Threatened species supplement

SW2: 4m to 6m buffer strip on intensive grassland

TE1: Planting standard hedgerow tree

TE11: Tree surgery

TE2: Planting standard parkland tree

TE9: Parkland tree guard - welded steel

WD3: Woodland edges on arable land

WD4: Management of wood pasture and parkland

WD5: Restoration of wood pasture and parkland

WD6: Creation of wood pasture

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Twite
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Twite *Linaria flavirostris*

Climate Change Sensitivity:	HIGH	Ability to Manage:	MEDIUM
Non climatic threats:	HIGH	Vulnerability:	HIGH

Summary

Once widespread and locally numerous, the twite *Linaria flavirostris* has declined almost to extinction in England, though the precise cause of the current population decline is not well understood. The species is at the southern edge of its NW European range in the UK, and bio-climatic projections suggest that its current range in England will become unsuitable by 2080.

Promoting the resilience of existing sites is a priority for adaptation management in the UK. This includes ensuring the provision of tall heather and bracken for nesting close to the moorland edge, a wide range of seed food sources throughout spring and summer close to breeding sites, and, on their wintering grounds, saltmarsh with high densities of glasswort and other pioneer marsh species available from late autumn to early spring.

Description

The twite is a small songbird of the finch family. It is approximately 14 cm long and has a wingspan of 23 cm. They are mainly brown, with dark streaking on the head and back, a pale belly, a buff-coloured face and neck, and have a long forked tail. Males and females are similar except for the colour of their rump, which is pink on males and used in display, and brown on females.

Ecology and distribution

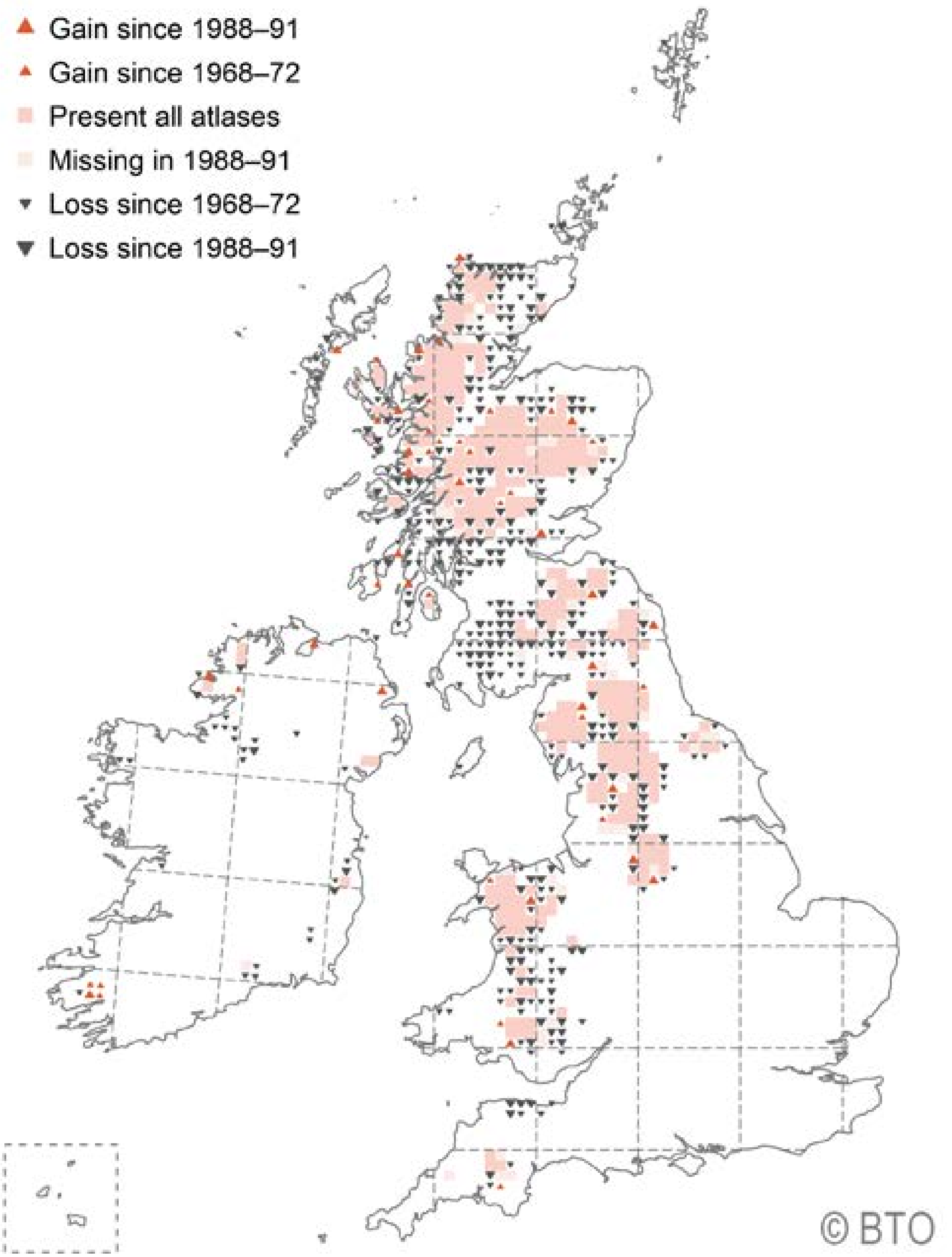
In the UK, most breeding twite occur in north-west Scotland, with small populations in upland areas of northern England and north Wales, and on the coast of Northern Ireland. In England, twite nest on open moorland and forage for seeds in flower-rich grasslands. They nest primarily in bracken *Pteridium aquilinum* and tall heather *Calluna vulgaris*, but will also use other dwarf shrubs and moorland grasses. Nests are placed on the ground, in vegetation, beneath boulders or on the ledges of cliffs and quarries (Orford 1973; Raine 2006). Birds commonly nest in loose groups, sometimes within a few metres, close to the moorland edge (Brown, Crick & Stillman 1995; Wilkinson & Wilson 2010). Twite feed mainly away from moorland, up to 3.5 km from nest sites (Raine 2006), and favour flower-rich meadows and pastures, roadside verges and other weedy areas. They feed on the seeds of a wide range of species, including annual meadow grass *Poa annua*, dandelion *Taraxacum officinale* agg., blinks *Montia fontana*, common sorrel *Rumex acetosa*, thistles *Cirsium* spp. and autumn hawkbit *Leontodon autumnalis*, with species being exploited as they become available (Raine 200; Wilkinson & Wilson 2010).

Twite are multi-brooded, with up to three successful broods in a single season, although these may overlap (Wilkinson & Wilson 2010). Clutches of 1-7 eggs are laid from late April to late July, with a complete nest cycle taking approximately 30 days (Brown, Crick & Stillman 1995; Raine 2006; Wilkinson & Wilson 2010). Adults breed in their first year. After fledging, the young tend to remain on the moor for the first few days before moving to flower-rich areas in the surrounding farmland. Here, birds congregate into flocks where they tend to remain within a few kilometres of natal areas, although some individuals roam widely (Raine *et al* 2006b), before winter migration in October.

While some birds remain in the Pennines through the winter, most twite breeding in the South Pennines and Peak District migrate to saltmarshes on the east and south-east coast of England, from Yorkshire south to Kent (Brown & Atkinson 2002; Raine *et al* 2006a). In winter, they favour pioneer marsh communities where they feed on the seeds of glasswort *Salicornia* spp., annual seablite *Suaeda maritima*, sea lavender *Limonium vulgare* and sea aster *Aster tripolium* (Brown & Atkinson 1996). The distribution of birds on saltmarsh, particularly in late winter, is strongly related to the density of glasswort seed remaining on the plants (Atkinson 1998). The proximity of suitable roost sites may also be important in determining habitat selection. Birds return to breeding areas between March and April.

The twite population in England has declined markedly since the end of the 19th century, when their distribution included most counties in northern England (Holloway 1996). The species is now restricted chiefly to the South Pennines, although declines in abundance and range are continuing (Raine *et al* 2009; Balmer *et al* 2013, Wilkinson *et al* 2018). Recent analyses suggest that breeding productivity and survival is low relative to estimates for this population historically (productivity) and to other populations in the UK (productivity and survival; Wilkinson *et al* 2019). Furthermore, annual breeding productivity in the south Pennines is substantially lower for pairs nesting in bracken than in heather, suggesting that the use of bracken as a nesting habitat may represent an ecological trap for this population. However, the precise mechanism underlying this difference between nest habitat types is not known and requires further research. Past declines have most likely been caused by the loss and degradation of suitable habitat in both upland breeding areas (as a result of changes in land use and farming practices) and wintering grounds (most likely due to changes in estuary shape, dredging and increased storminess), but the relative importance of these factors and precise cause of the recent decline is not known (Atkinson 1998; Brown & Grice 2005; Raine 2006).

Historic changes in the distribution of the twite
(reproduced with permission of the BTO, from Balmer *et al* 2013)



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Confidence in climate change impacts[39]

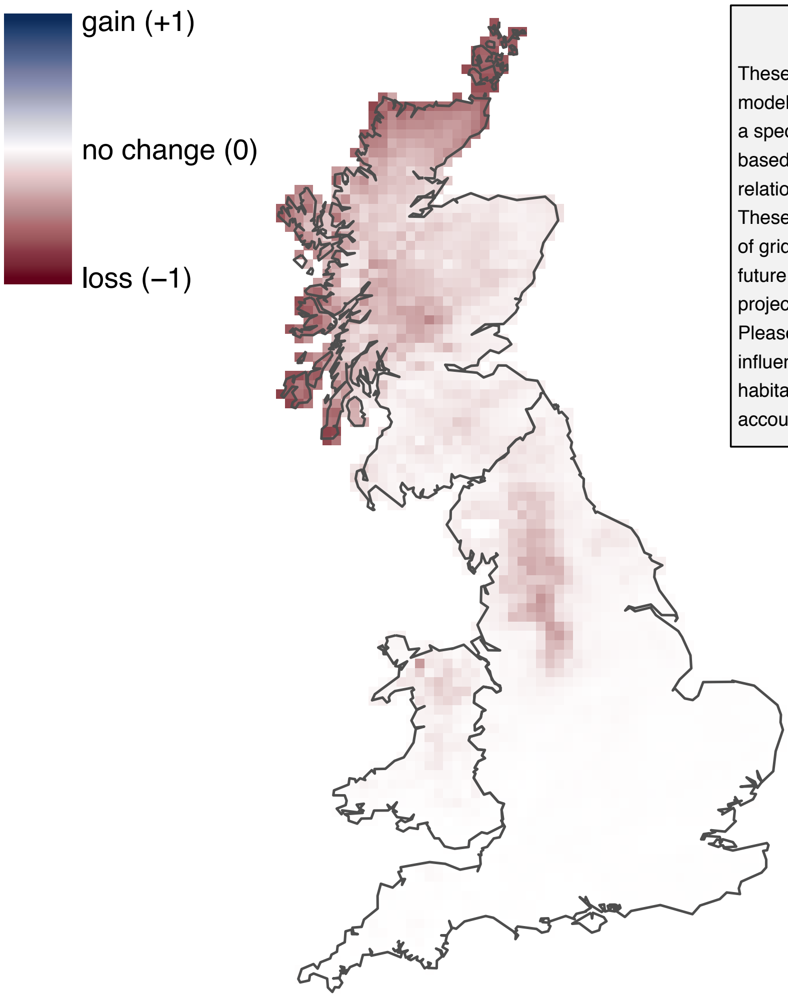
Distribution change: **HIGH CONFIDENCE** Mechanism: **LOW CONFIDENCE**

The current breeding range of twite in northern England and Wales is projected to become climatically unsuitable in the future, with suitable climate conditions limited to northern and parts of central Scotland by 2080 (Huntley *et al* 2007).

On their wintering grounds, rises in relative sea-levels combined with hard sea defences ('coastal squeeze') may cause further reductions in the area of saltmarsh, with the pioneer communities favoured by twite being the first to be affected (Brown & Grice 2005; Natural England & RSPB 2014; but see also Hughes & Paramour 2004).

39 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Projected change in potential distribution of twite in the UK with a temperature rise of 2°C (Pearce-Higgins *et al* 2015).

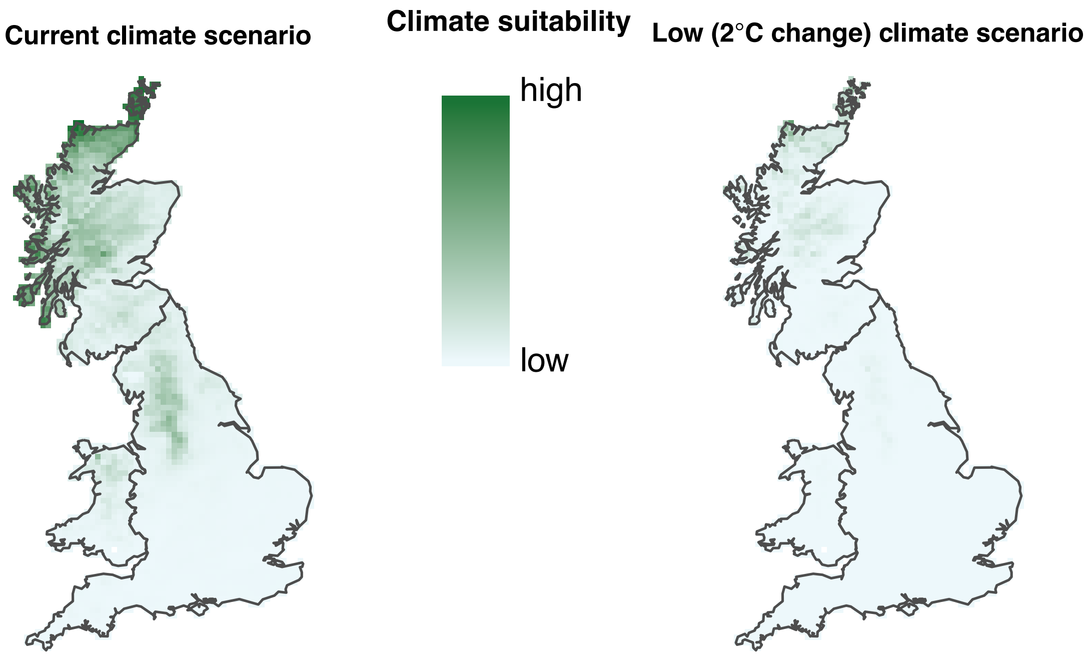


Climate suitability

These maps are created using statistical models which describe the probability that a species will be found in a 10 km grid square, based on its current distribution and its relationship to a number of climatic variables. These can be used to model the suitability of grid squares for a species under possible future climates when climate change projections are taken into account. Please note that other variables that influence species distributions, such as habitat and land–use change, are not accounted for in the modelling process.

Confidence of change

An assessment of the available data and other factors, as part of Natural England's Research Report NECR175, suggests that our confidence in this projection is very high. N.B. many confidence assessments are rated as low because there is a lack of published information on the likely influence of climate on the species concerned.



Created by:	University of York	Created for:	Natural England	Created on:	August 17 2016

Further information on these projections can be found in the introduction to the species section (Part A, Section 3 and Part B Section 5). Note that this is a guide to where a species may be able to survive, it does not capture other issues such as habitat availability and fragmentation – see text above for further details. Contains public sector information licensed under the Open Government Licence v3.0. Please also see acknowledgement and copyright at the beginning of this manual.

Please read this case study alongside the relevant habitat sheets.

Adaptation options

Climate change projections suggest that for populations in England and Wales, where there are no adjacent areas which are likely to have suitable climate conditions in future, adaptation should focus on maintaining existing habitat patches in an optimum condition to reduce the likelihood of other, non-climatic, factors exacerbating population declines. In particular, conservation efforts could identify those areas which might be least subject to climatic change ("refugia") such as on the northern slopes of hills, and which could be important areas to help maintain populations in the future. However, to ensure the maintenance of twite in the UK it is important that adaptation efforts are also focused on the Scottish Highlands where there is overlap between current and future suitable climate conditions. Here, adaptation should focus on ensuring the quality of existing habitat before considering restoration of adjacent degraded areas. Research is necessary to identify the mechanisms of climate change impacts and ways of promoting resilience and recovery. Monitoring to evaluate the efficacy of conservation actions, particularly in southern parts of the range, will also help to inform adaptation measures.

Potential adaptation actions for the twite include:

- At sites supporting breeding twite, ensure optimum management of moorland through grazing to provide a mosaic of tall heather and mature bracken with a deep litter layer for nesting (although note that for bracken this should be reviewed dependent on further work to understand its potential role as an ecological trap). Protect nesting areas from burning with fire breaks, and from inappropriate grazing and afforestation.
- Identify those sites that might be least subject to climate change, as potential refugia where conservation action might be most sustainable.
- Within 1.6 km of twite nesting sites, and ideally as close as possible, ensure optimum management of meadows, pastures and other weedy areas through cutting, grazing and, where necessary, re-seeding to provide abundant seed food sources for foraging from spring arrival through to late summer.
- At existing sites supporting wintering twite, ensure optimum management of saltmarshes to provide high seed densities of glasswort and other important food-plants, particularly in sheltered areas that retain seeds in late winter.
- Monitor twite populations and the efficacy of conservation actions to assess the requirement for further adaptation measures.
- Undertake research to identify the causes of change, mechanisms of climate change impacts and factors that promote population resilience.

Relevant Countryside Stewardship options

CT3 Management of coastal saltmarsh

CT5 Creation of inter-tidal and saline habitat by non-intervention

CT7 Creation of inter-tidal and saline habitat on intensive grassland

GS6 Management of species-rich grassland

GS7 Restoration towards species-rich grassland

GS13 Management of grassland for target features

GS15 Haymaking supplement

UP3 Management of moorland

Case Studies

Twite recovery project

RSPB and Natural England have undertaken a trial programme of conservation measures in an attempt to arrest the decline of twite breeding in the south Pennines. Since 2009, management to increase the availability of seed food sources throughout the breeding season has been implemented via Higher Stewardship Scheme (HLS) agreement options on farmland close to breeding sites. The main conservation measures have involved the restoration of flower-rich meadows and pastures through re-seeding with twite food plants, and adjusting cutting dates and grazing regimes. The project has also sought to secure the appropriate management of moorland for nesting. Results from monitoring the twite population and habitat responses to conservation action during 2008-16 showed further declines in abundance and that some of the habitat interventions had yet to deliver the expected improvements, possibly due to their immaturity. Further work to improve the quality of these sites for foraging, including piloting some management trials, is ongoing. Recent population modelling suggests that conservation efforts should focus on interventions to increase first-year survival as well as breeding productivity.

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White faced darter
© Barry Henwood

White faced darter
Leucorrhinia dubia Vander Linden

Climate Change Sensitivity:	HIGH	Ability to Manage:	MEDIUM
Non climatic threats:	MEDIUM	Vulnerability:	HIGH

Summary

The white faced darter has been lost from many sites in the south and midlands. Across its range, the loss and degradation of lowland peat bogs has been the main cause of its decline, but the loss from its southern sites suggests that the warming climate may be having an impact. The species has been well studied, and successfully reintroduced to sites where habitats have been restored. The restoration of former sites or the creation of new sites in parts of the country that will remain climatically suitable for the species will offer the best approach to building the resilience of the species within England.

Description

The white-faced darter is a small dragonfly with a characteristic white face that gives it its name. The male is mainly black with scarlet and orange markings. Females are also predominantly black but have pale yellow markings. Its dark colouration means that it is able to warm up quickly in the sun, and therefore is well adapted to cool conditions.

Ecology and Distribution

The white faced darter is a rare dragonfly found mainly in Scotland, but also in the north of England, it has now been lost from all of its southern sites (Pam Taylor pers. comm.).

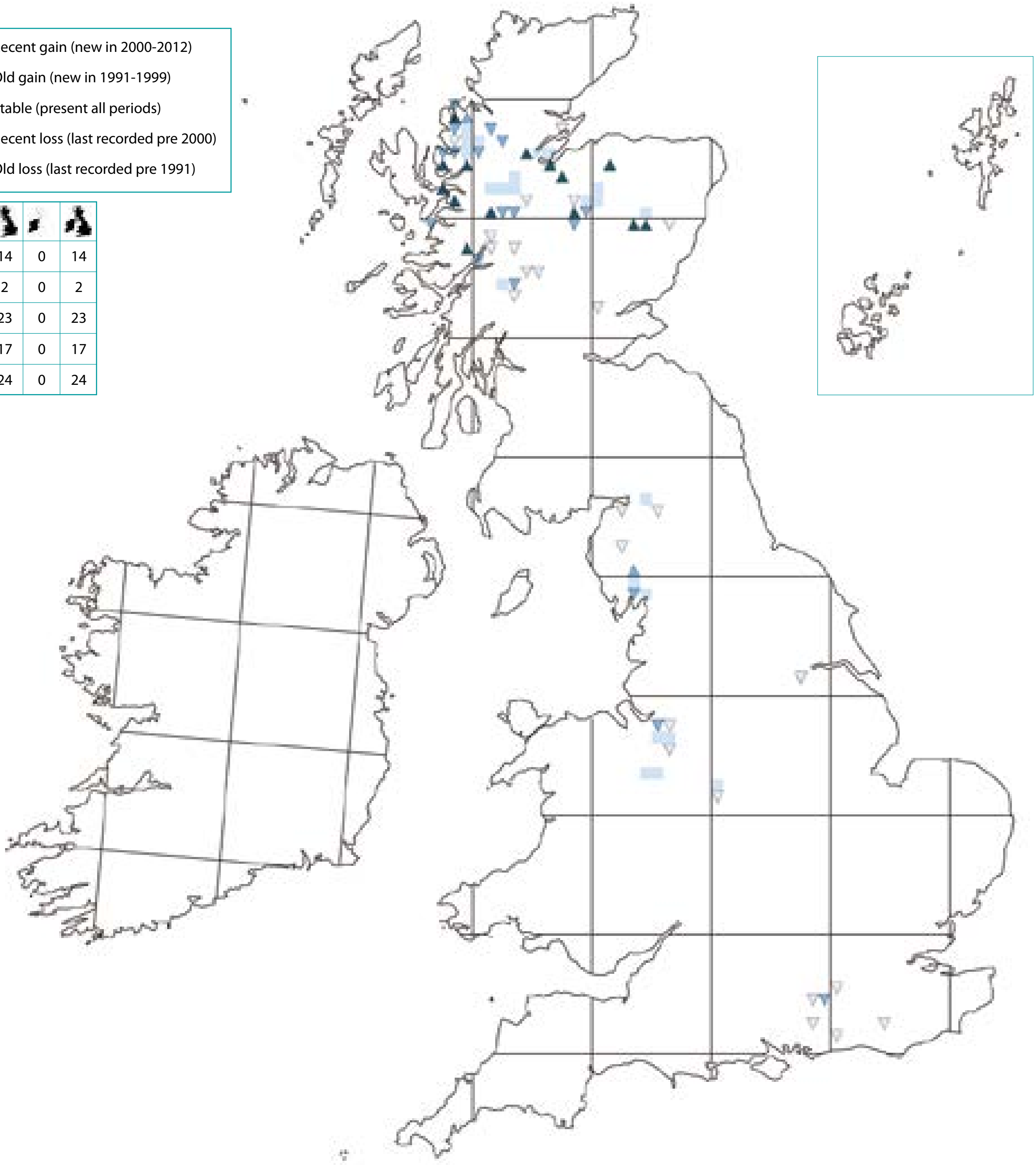
It is a species of lowland peatbogs, and prefers relatively deep, low nutrient, acidic pools with marginal rafts of sphagnum in which to breed. It has also been found to use waterlogged sphagnum in depressions devoid of standing water (Beynon & Daguet 2005). In addition to aquatic habitats it also requires scrub or woodland, which provides important roosting and feeding sites.

The larvae are aquatic and spend two or three years among the sphagnum moss feeding on other aquatic invertebrates. Although found predominately in acidic waters, research suggests that acidity is important mainly because it reduces predation by fish (Henrickson 1988; Johansson & Brodin 2003). The larvae actively hunt during the day and are susceptible to predation. Acidic conditions prevent the presence of fish, resulting in reduced predation pressure on the larvae. Adults emerge in late May and fly for three to four weeks, up to the end of July. Research suggests that adults return to the site from which they emerged to breed.

The white faced darter has declined significantly in England in the last 35 years (Powney *et al* 2014), and is now present at less than half the sites in which it occurred in the mid-20th century. Most of this decline is associated with the loss or degradation of lowland bog habitat, through activities such as land drainage, peat cutting and afforestation. More recently, it has been lost from most of its southern sites, a pattern of decline replicated across much of Europe (De Knijf 2008; Ott 2010). This is consistent with the impacts of climate change outlined below.

The British Dragonfly Society records for white faced darter are shown on the map below (10km grid scale).

Presence of white faced darter records records, 10km².



	14	0	14
	2	0	2
	23	0	23
	17	0	17
	24	0	24

Map © Natural Environment Research Council and British Dragonfly Society (2014).

© rspb-images.com

Confidence in climate change impacts[40]

Distribution change: **HIGH CONFIDENCE** Mechanism: **LOW CONFIDENCE**

The emergence of the white faced darter has been shown to be sensitive to changes in temperature, and the average emergence of adults has advanced by over three weeks in the last twenty years (Parr 2010).

In Europe, competition from other dragonfly species expanding their range due to climate change may have played a role in its decline, while laboratory studies show that the white faced darter larvae have reduced growth rates in warmer conditions (Suhling & Suhling 2013).

The impact of climate change is likely to operate primarily through the effect on the extent and quality of suitable habitat (Elo, Penttinen & Kotiaho 2015). Projected changes in rainfall are likely to have adverse impacts on the hydrology of many lowland bogs, especially in the south of England. Summer warming and reduced rainfall are likely to lead to reduced water levels in summer, with a knock-on impact on the development of sphagnum. Lower water levels combined with warming will also adversely affect water quality, resulting in habitat degradation. Potential indirect impacts of climate change such as increased abstraction may exacerbate the situation. Periodic drying leading to habitat degradation has been shown to have caused the loss of the white faced darter from sites in Germany (Ott 2010). Looking ahead, it is likely that the area with climatic conditions suitable for the white faced darter will contract further, and many southern sites will increasingly lie outside its optimal climatic zone.

Please read this case study alongside the relevant habitat sheets.

40 An assessment of the strength of evidence that distributions are changing and the mechanisms causing change are understood. Refer to Part B, section 5 of the species section introduction for more information.

Adaptation options

Reversing the historic loss of suitable sites within its existing range is likely to be the most effective adaptation action in the UK. Restoration or creation should focus on areas likely to remain climatically suitable for the species, most likely in the north of the country. The long term viability of populations towards the south of its range may make successful re-establishment harder.

- Ensure optimum management of existing sites through the appropriate management of water levels and water quality to preserve oligotrophic acidic conditions; and control of scrub, trees and aquatic vegetation to maintain or create areas of open water with floating marginal sphagnum.
- Avoid introducing fish to sites, and ensure acidic conditions to prevent fish colonising sites naturally. If fish are present, the promotion of large sphagnum mats may help to reduce predation by providing cover for the dragonfly larvae (Henrikson 1993).
- In many cases, the removal of encroaching scrub and trees is required to ensure suitable open water and sphagnum habitat. However, in southern sites, some trees and cover may be beneficial in providing shade and reducing water temperature.
- Assisted reintroduction should be considered where restored sites are distant from existing colonies, as the species' preference for returning to its emergence site means it has relatively poor dispersal ability. The translocation of nymphs or the seeding of pools with egg-containing sphagnum from existing sites are the best approaches.
- In those sites where climate change related declines are expected, establish programmes to monitor population trends and the effectiveness of interventions.
- If it is suspected that climate change is responsible for losses, undertake research to identify the mechanisms driving these losses.

Relevant Countryside Stewardship options

WT4 Management of ponds of high wildlife value (100 m2 or less)

WT5 Management of ponds of high wildlife value (more than 100 m2)

WT10 Management of lowland raised bog

FM2: Major preparatory works for Priority Habitats (creation and restoration) and Priority Species.

Case Studies

Foulshaw Moss Nature Reserve

Cumbria Wildlife Trust and the British Dragonfly Society reintroduced the white-faced darter to Foulshaw Moss Nature Reserve in South Cumbria in 2010. This was the first attempt to reintroduce the white-faced darter dragonfly anywhere in the UK.

Delamere Forest

Cheshire Wildlife Trust, the British Dragonfly Society and partners reintroduced the white-faced darter to Delamere Forest in Cheshire, after an absence of more than a decade. The project has developed detailed methodologies for translocation and monitoring.

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Arctic charr
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Whitefish *Coregonus lavaretus*, Vendace *Coregonus albula*, and Arctic charr *Salvelinus alpinus* (Linnaeus)

Climate Change Sensitivity:	HIGH	Ability to Manage:	LOW
Non climatic threats:	HIGH	Vulnerability:	HIGH

Summary

Climate change is a threat to whitefish, vendace and Arctic charr in England, and this is exacerbated by other environmental pressures such as increased colonisation of non-native species and nutrient enrichment. Nutrient enrichment can result in deoxygenated conditions in deep water, where the water is coolest, resulting in a contraction of suitable habitat for these species. Climate change is predicted to increase lake water temperatures, and increase sediment loads and nutrient concentrations due to more storms and wetter winters, resulting in increases in run-off from the catchment bringing sediment and nutrients with it, with a resulting loss of spawning habitat.

Restoring naturally functioning lake habitat by limiting inputs of nutrients and sediments and restoring natural hydrological regimes will benefit whitefish, vendace and Arctic charr populations. However, the long-term future of some standing waters as habitat capable of supporting these species is confounded by climate change. Climate change is predicted to exacerbate eutrophication and sediment loads, and increase water temperatures.

In response, every effort should be made to restore natural function to the habitat, but alternative populations may need to be established to ensure the survival of the species within their natural English range. If translocations of these fish species to new water bodies are planned, the indigenous fish populations of the receiving water body must be considered. Whitefish, vendace or Arctic charr should not be translocated to water bodies containing other rare fish species which may suffer either competition or genetic pressures.

The threats posed by non-native species are difficult to control once colonisation has occurred. It is possible that new eradication methods may become available in the future but the prospect of this seems limited. Therefore, it is imperative that biosecurity measures are maintained to reduce the risk of initial colonisation by both non-native and locally non-native species.

Description

These three species of fish are treated together in this account as they are all species restricted to cool, deep lakes in northern Britain, with many of the same threats.

The whitefish *Coregonus lavaretus* is the most widely distributed coregonid in the UK. This geographical distribution is reflected in the species having three long-standing common names in the UK, schelly (or skelly) in England, powan in Scotland and gwyniad in Wales. It is a streamlined but heavily built fish with a typical maximum length of 30-35 cm and weighing up to 400 g. British populations are resident in lakes throughout their lifecycles and require cool water with relatively high dissolved oxygen levels. They typically spend daylight hours in deep water (>20 m) and move into marginal areas at night to feed. Spawning takes place from late December to early February and requires clean gravels around inshore areas at depth <4 m. The fry emerge after 90-100 days, depending on water temperature. Whitefish shoal throughout their lifecycle, with juveniles feeding on zoo-plankton and adults selecting benthic macroinvertebrates.

Whitefish. © Colin W. Bean

Vendace. © Ian J. Winfield

The vendace *Coregonus albula* has an extremely limited distribution in the UK and is considered the UK's rarest fish. It is a streamlined and slender fish with a distinctive leading lower jaw, typically up to 25 cm in length and weighing up to 150 g. British populations are found in oligotrophic or mesotrophic lakes and maintain a shoaling habit throughout their lifecycles. They are considered a glacial relict and require cool water with high oxygen concentrations. During daylight hours, vendace remain close to the lake bed at depths >10 m before rising through the water column at night to feed on zooplankton. Spawning occurs on clean, inshore gravels from late November to mid-December, with fry emerging during the following March and April.

The Arctic charr *Salvelinus alpinus* is thought to be another glacial relict species and in England and Wales is only found in large, deep, cold lakes. However, it has the ability to survive in much more productive systems at other locations. In the UK, even where access to the marine environment is possible, it does not attempt to revert to the anadromous habit seen in other countries. Arctic charr are streamlined and resemble a slender trout, typically reaching 20-25cm in length and weighing up to 170g; however, larger specimens up to 35cm/600g may occur. They tend to occupy offshore habitats as a result of inter-specific competition with other fish species, and come inshore to spawn. Spawning usually takes place from October to December, however 'spring' spawnings between February and March have also been recorded. Clean gravels are required and may be located around lake margins, inlet streams/rivers and occasionally deeper water areas within the lake.

Ecology and Distribution

The whitefish is widespread in northern Europe; however, in the U.K. it is restricted to a number of sites in the Lake District (Brothers Water, Haweswater, Red Tarn, and Ullswater), Loch Eck and Loch Lomond in Scotland, and Llyn Tegid in Wales. The species shows considerable genetic and morphological variation between sites. Attempts have been made to establish refuge populations of whitefish in Small Water and Blea Water in the Lake District. Egg incubation was very successful at both sites and in late 1997 surveys recorded young whitefish at Small Water, but not at Blea Water. In subsequent years, surveys at Small Water have recorded an established whitefish population, and anglers fly fishing for brown trout have occasionally reported catching adult whitefish at both locations. Similar reintroductions of whitefish have been undertaken at Carron Reservoir and Sloy Pond in Scotland and to Llyn Arenig Fawr in Wales.

Vendace occurs in lakes across north-west Europe (northern Scandinavia and north-west Russia to the north, north Bavaria to the south, English Lake District to the west and western Russia to the east). In England, vendace is found in mesotrophic Bassenthwaite Lake and oligotrophic Derwent Water. These lakes are connected by the River Derwent. As well as the natural difference in trophic status, Derwent Water is slightly deeper and has a much smaller catchment than Bassenthwaite Lake. While Derwent Water has consistently supported vendace, none were found in Bassenthwaite Lake from 2001-2013 despite specific searches. Since 2013 a limited number of individuals have been found in Bassenthwaite Lake, suggesting the range may not have declined as previously suspected, and may be recovering, although it is premature to be confident about this.

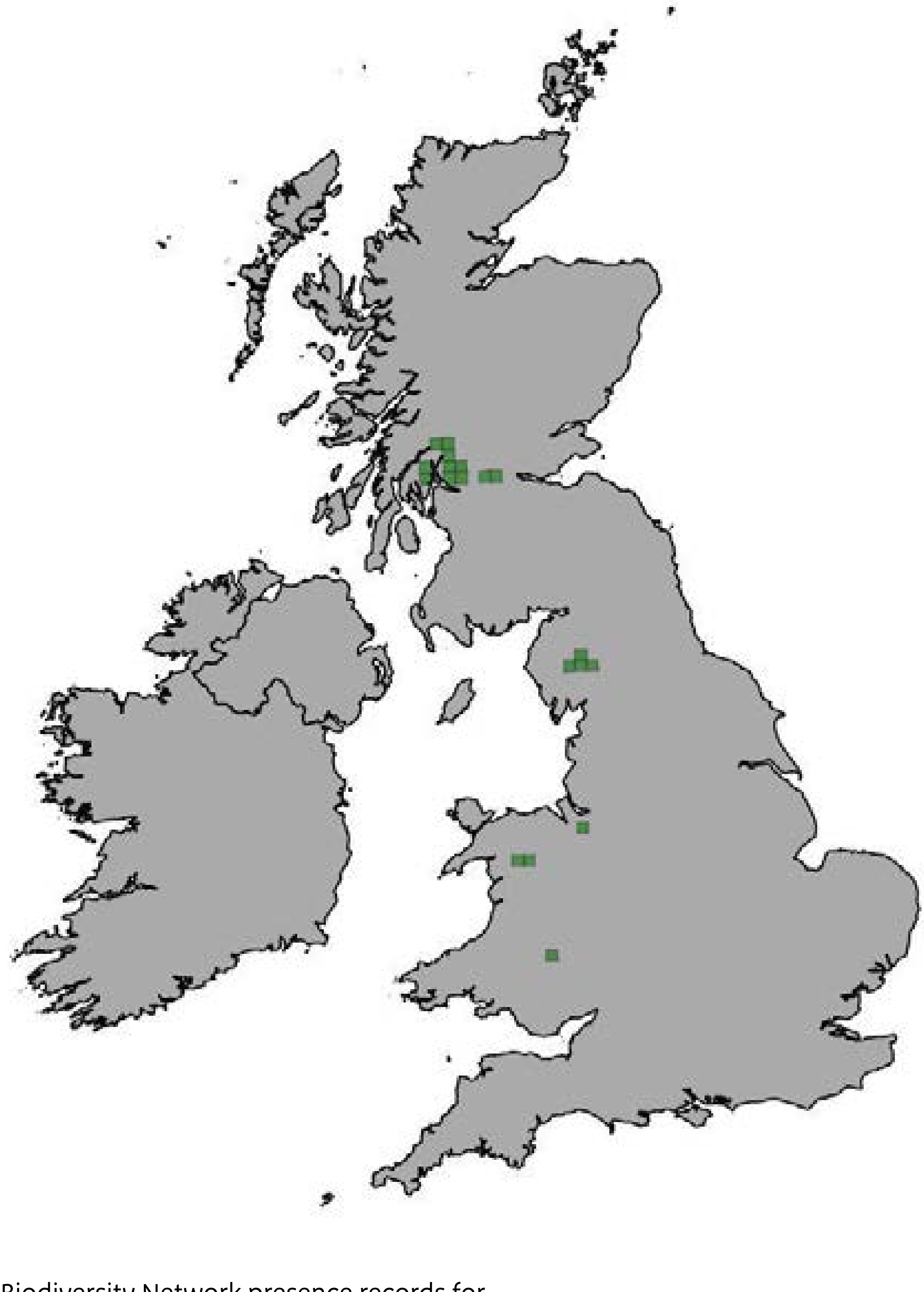
A very high variability is reported for all morphological characters between the many populations referred to as *C. albula*. The Derwent Water and Bassenthwaite Lake populations are distinct from *C. albula* populations from the eastern Baltic basin, but it is similar to some populations from the western Baltic.

Due to concerns for the conservation of this species, attempts have been made to establish refuge populations using fish from both Derwent Water and Bassenthwaite Lake. This has included attempts to establish populations at Sprinkling Tarn in the Lake District. There have been no reports of success from the site, but this may be due to a lack of sampling effort. However, progeny from fish collected from Bassenthwaite Lake have successfully been established in Loch Skeen, Scotland. Although it is still too early to state with confidence, 2016 surveys of the Loch Skeen vendace population appeared to indicate a strong population.

Arctic charr ***Salvelinus alpinus*****, male swimming over the gravels, Ennerdale Water, Cumbria, November.**
© Jack Perks (rspb-images.com)

The Arctic charr is a cold-loving, salmonid fish which is distributed throughout the temperate and subarctic regions of the northern hemisphere. It is an anadromous species in the northern part of its distribution, but in the southern part, including Britain and Ireland, it is non-migratory and confined to fresh waters. Natural populations in the south of its distribution are believed to have been derived from anadromous stocks which dispersed at the end of the last ice age but were then isolated in a variety of lakes as the climate warmed. All stocks in Britain and Ireland are found in lakes, even though many are located with Atlantic salmon *Salmo salar* and sea trout *Salmo trutta*, indicating that migration to and from the sea is physically possible in many cases. In Britain and Ireland, most populations of Arctic charr have been isolated from each other for thousands of years and have developed a variety of genetic and morphological variations. The differences between some populations are so great that many were originally described as distinct species. This species is now suffering a recent and widespread decline in the UK.

Presence of whitefish records, 10km², NBN Atlas

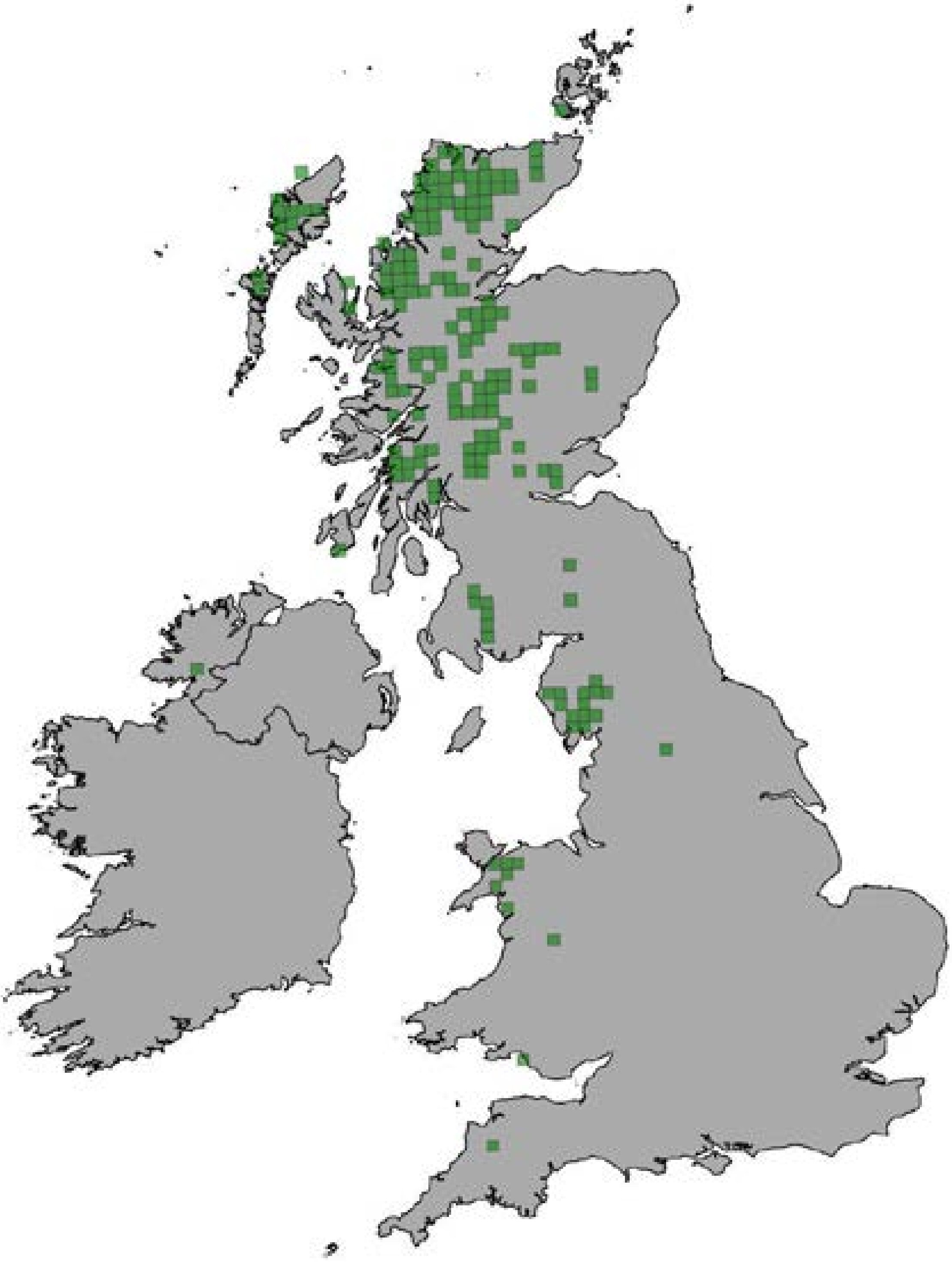


The National Biodiversity Network presence records for whitefish are shown on the map above (10km grid scale). (See **terms and conditions**, see Appendix 1 for the list of datasets included)

Presence of vendace records, 10km², NBN Atlas

The National Biodiversity Network presence records for vendace are shown on the map above (10km grid scale). (See **terms and conditions**, see Appendix 1 for the list of datasets included)

Presence of Arctic charr records, 10km², NBN Atlas



The National Biodiversity Network presence records for Arctic charr are shown on the map above (10km grid scale). (See **terms and conditions**, see Appendix 1 for the list of datasets included)

Climate Change Impacts

Climate change is considered to be a threat to all three species in England, and this is exacerbated by other environmental pressures such as increased colonisation of non-native species and nutrient enrichment. Nutrient enrichment can result in deoxygenated conditions in deep water, where the water is coolest, resulting in a contraction of suitable habitat for these species. Climate change is predicted to increase lake water temperatures, and increased sediment loads and nutrient concentrations are expected due to more storms and wetter winters, resulting in increasing sediment and nutrient run-off from the surrounding catchment. This could also result in a loss of spawning habitat.

The results of modelling to assess the long-term suitability of Bassenthwaite Lake as a habitat for vendace suggest that its probability of long-term viability is extremely low (Elliott & Bell 2011). Derwent Water is more likely to support vendace as it is expected to be more resilient to the impacts of climate change than Bassenthwaite Lake. This is because being naturally oligotrophic, Derwent Water is further from the nutrient concentration limits that vendace can tolerate, has a smaller catchment (despite a similar lake size) to deliver nutrients, and is slightly deeper.

A similar investigation found that 10 of the 11 Arctic charr populations studied along the latitudinal distribution gradient of this species in the UK showed significant recent declines in abundance, with only the most northerly population surveyed (Loch of Girlsta in the extreme north of Scotland) exhibiting a significant increase. Declines observed in the Arctic charr populations of Scotland, England and Wales are likely to have resulted from a number of environmental factors, some of which may be unrelated to climate change. However, the hypothesis that the observed widespread decline of Arctic charr in the UK can be attributed at least in part to climate change is supported.

Please read this case study alongside the relevant habitat sheets.

Adaptation Options

Restoring naturally functioning lake habitat by limiting inputs of nutrients and sediments and restoring natural hydrological regimes will benefit whitefish, vendace and Arctic charr populations. However, the long-term future of some standing waters as habitat capable of supporting these species is threatened by climate change. As a consequence, alternative populations may need to be established to ensure the survival of these species within their natural English range.

This is particularly relevant to the vendace, whose current range is thought to be limited to two lakes in the Lake District, and where assisted migration, perhaps to a higher altitude, may be possible. However, even if areas of suitable habitat capable of supporting a sustainable vendace population could be identified there is no guarantee of success. Of the four sites where attempts have been made to establish a new vendace population in the UK, only one is known to be successful.

The threats posed by non-native species are difficult to control once colonisation has occurred. Removing introduced fish species is not currently considered technically feasible, as any methods which could control the invasive species would also impact other fish species, including whitefish, vendace and Arctic charr. It is possible that new eradication methods may become available in the future but the options for this seem limited. Therefore, it is imperative that biosecurity measures are maintained to reduce the risk of initial colonisation by both non-native and locally non-native species.

Although charr will feed on zooplankton, they will also feed on many other sources of food such as macroinvertebrates and therefore may not compete directly and aggressively with vendace. Whitefish may feed exclusively on zooplankton or more generally on macroinvertebrates, indicating that competition with vendace may be either intense or more limited. The feeding preference of whitefish may determine the intensity of the competition with vendace. This was demonstrated in a Norwegian study by Bøhn, & Amundsen (2001). They found damage to an indigenous zooplankton feeding whitefish population due to an introduction of vendace into a water body where vendace were not previously resident. However, in a similar water body containing a macroinvertebrate feeding whitefish population, the whitefish population remained largely unaffected by the vendace introduction.

Due to the genetic closeness and plasticity of the coregonids, hybridisation may be technically possible. However, under field conditions spawning triggers such as water temperature are likely to separate the different species.

When these factors are taken into consideration, the precautionary principle dictates that whitefish, vendace or Arctic charr should not be translocated to water bodies containing other rare fish species which may suffer either competition or genetic pressures.

Relevant Countryside Stewardship options

To address the in-lake and wider catchment issues impacting negatively on coregonid and Arctic charr populations in England, Countryside Stewardship may be used to fund measures to restore the naturally functioning habitat required for sustainable fish populations. Countryside Stewardship includes a number of options intended to reduce run-off and siltation of spawning habitat, improve water quality, and reduce water temperatures within tributaries. Relevant options to consider include:

SW1 4 - 6 m buffer strip on cultivated land

SW2 4 - 6 m buffer strip on intensive grassland

SW4 12 - 24m watercourse buffer strip on cultivated land

SW5 Enhanced management of maize crops

SW6 Winter cover crops

SW7 Arable reversion to grassland with low fertiliser input

SW8 Management of intensive grassland adjacent to a watercourse

SW9 Seasonal livestock removal on intensive grassland

SW10 Seasonal livestock removal on grassland in SDAs next to streams, rivers and lakes

SW11 Riparian management strip

SW12 Making space for water

UP3 Management of moorland

UP5 Moorland re-wetting supplement

Case Study

Due to the rapidly declining vendace population at Bassenthwaite Lake during the early 1990's, efforts were made to establish new vendace refuge populations in both Scotland and England. Care was taken to avoid the creation of new conservation problems at the recipient site and to maintain the genetic integrity of the refuge populations. The former requirement required extensive searches for, and assessments of, potential sites against a wide range of criteria, including the characteristics of the receiving fish community. The latter requirement meant avoiding the use of hatcheries completely or limiting their use to eyed-egg or swim-up larvae stages, to guard against any inadvertent but significant genetic selection.

Derwent Water. © Dave Ottewell

Progeny from the Bassenthwaite Lake and Derwent Water populations were kept separate and egg collections were made a number of times over the course of the spawning season and in more than one calendar year. Following the above approach, a total of 35 female vendace were stripped for eggs at Bassenthwaite Lake in 1997 and 1999 and a total of approximately 65,000 eggs and larvae were introduced during the following springs to Loch Skeen in Dumfries and Galloway, south-west Scotland. Following the introduction, anglers fishing for brown trout at Loch Skeen reported unintentionally catching vendace at this locality. An initial survey in 2003, demonstrated that a reproducing vendace population had become established in the loch. A more comprehensive survey was carried out in 2007 by a combination of survey gill netting and hydroacoustics. The survey identified a vendace population density estimated at 231.7 fish per hectare, with individuals ranging in age from one to six years. A follow up survey in 2016 again found a healthy vendace population, clearly indicating that a viable refuge population had become successfully established.

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Part 4

Green infrastructure and climate change

Introduction

Green infrastructure is defined in the **National Planning Policy Framework** (2012) 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 section of the manual considers how green infrastructure can support climate change adaptation within urban areas. It describes the most likely impacts of climate change, and sets out information and evidence on how different forms of green infrastructure can help to address these issues. The section is aimed at the conservation sector as well as others who work in planning, sustainable development and who work in and with local partnerships and Local Planning Authorities.

Within towns and cities, the natural environment is often degraded and fragmented. The incorporation of new green infrastructure (including green space, open water – often referred to as blue space - and brownfield land) within settlements can help to provide new habitats for wildlife, while also improving the quality of life for urban communities and helping us to adapt to some of the effects of climate change. For a general overview of green infrastructure and its multi-functional benefits, Natural England has published **guidance** on green infrastructure planning and delivery.

The natural environment also has a crucial role in making urban landscapes liveable. Using nature based solutions, through the delivery of green infrastructure, to create successful places, for both humans and wildlife, is becoming increasingly understood and recognised as an essential component of nature conservation and ecosystem based adaptation.

Planning for and delivering green infrastructure is a key way to deliver and support climate change adaptation. If designed and located well, green infrastructure can provide multiple ecological benefits, such as creating and improving wildlife sites and enhancing ecological networks. It can also provide societal benefits such as increased recreation resources, flood risk management, and bringing people into contact with nature, thereby improving quality of life. Key adaptation benefits of green infrastructure include (**Natural England 2009**; **North West climate change action plan & GRaBS report 2010**):

- Managing temperature
- Managing water supply
- Managing river and coastal flooding
- Managing surface water
- Reducing soil erosion
- Helping species adapt
- Managing visitor pressure.

Green infrastructure can include a wide range of measures that enhance both the natural environment and the built environment. These include green roofs and walls, green and blue spaces and green travel routes. Green infrastructure can also include street trees, gardens, parks, rivers, wetlands and coastal areas. Sustainable urban development, including through green infrastructure delivery, is a key and growing adaptation delivery mechanism, and as such forms a significant area of work for Natural England and its partners.

Urban climate change impacts

Climate change will impact on urban areas in a number of ways. Many urban areas are already vulnerable to extreme weather events such as high rainfall and heatwaves. These events can lead to flooding and problems with localised areas of higher temperatures caused by modifications to the land surface and waste heat generated by energy use, often known as urban heat islands. Climate change will increase the severity and frequency of these extreme events. Impacts are likely to be greatest in areas that lack green open spaces and where natural processes such as drainage have been disrupted (**UK Climate Change Risk Assessment Evidence Report 2017**).

Biodiversity in urban areas will also be affected by climate change. As with rural areas, individual species may experience shifts in their range and distribution, and changes in the timing of natural events (e.g. as a result of earlier springs) could have important consequences for the interactions between species (Morecroft & Speakman 2015). These impacts could lead to changes in the composition of species' communities. Some urban areas can be quite hostile to wildlife, with small, fragmented areas of habitat and many physical barriers to movement, and the ability of species to move and adapt to change may be restricted.

The table below summarises the most significant potential impacts of climate change on urban biodiversity and urban communities. These are addressed in more detail in the following sections. Many of the impacts on biodiversity will also be experienced outside of urban areas, and are covered in more detail in the habitats and species sections of this manual.

Cause	Consequence	Potential impacts on urban biodiversity	Potential impacts on urban communities
More severe and more frequent rainfall events.	Flooding – surface water, coastal, and fluvial.	Increased frequency and intensity of rainfall causes flooding, waterlogging and longer periods of inundation, reducing the available habitat area available for various life cycle stages (e.g. foraging, breeding and hibernating). This is a particular issue for urban rivers and watercourses, many of which are heavily modified and canalised. Sudden downpours can lead to surges of water which wash species out as there are no backwaters etc. in which to hide from the current. Increased soil/sediment erosion and deposition. Changes in species composition due to changes in climatic factors that affect breeding success or mortality rates. Increased risk of pollution, especially if sewers and waste water treatment facilities flood.	Costs and disruption caused by flooding of residential, business and recreational areas, and to transport and energy infrastructure. One of the biggest challenges is surface water flooding due to lack of permeability and inundation of drainage systems. Reduction in service provision due to flooding e.g. emergency services, schools, hospitals, etc. Mortalities, injuries and mental health impacts of flooding. Increased soil erosion or sediment deposition affecting infrastructure. Impacts on drinking water provision and the costs associated with sewage removal and damage repair.

Cause	Consequence	Potential impacts on urban biodiversity	Potential impacts on urban communities
Reduced summer rainfall	Drought	Changes in species composition, as species that require specific hydrological conditions may be affected. Increased fire risk due to dry vegetation and ground conditions. Increased individual mortality, especially if water availability is severely reduced. Low water flows/volume and resultant pollution concentrations could affect freshwater habitats and species. Low water flows/volume can also result in a reduced oxygen content within the water and an increased risk of algal blooms, which can have a detrimental effect on freshwater habitats and species.	Increased fire risk to dried out vegetation (e.g. heathlands, grasslands and woodlands) and proximity to built-up areas. Low flows/volume could affect water availability and lead to restrictions on use. Pollution concentration and algal blooms in water bodies could restrict recreational use. Water shortages and restrictions on use. The ability of green infrastructure to provide some ecosystem services will decrease if it is drought stressed.
Increased mean temperatures	Urban Heat Island effect Seasonal changes	Changes in species distribution and community composition as some species may not survive in higher temperatures. Higher temperatures may facilitate the spread of invasive species and diseases. Higher temperatures will lead to a longer growing season, which could lead to increased vegetation growth. Altered phenology and species interactions, e.g. the timing of birds hatching and the availability of food supplies may be mismatched. Increased water temperatures could affect aquatic species with specific temperature requirements. Species with winter chill requirements may be affected e.g. some trees require a winter chill period in order to fruit well in the following season.	Travel disruption caused by damage to transport infrastructure (e.g. rail buckling, road melting), and the resulting repair needs. Impacts on health and wellbeing due to heatwaves e.g. increased instances of heat stroke and respiratory illness. Overheating in buildings in the summer could lead to a loss of productivity (UK CCRA Evidence Report 2017). Warmer summers could exacerbate air pollution issues. For example, air pollution can rise in periods of hot, calm weather, particularly ground level ozone concentrations (UK CCRA Evidence Report 2017). Increased energy demand for summer cooling, and potentially reduced energy demand for heating in the winter. Heat-related damage and disruption to energy infrastructure, and energy transmission efficiency losses.

Cause	Consequence	Potential impacts on urban biodiversity	Potential impacts on urban communities
Sea level rise	Increased risk of coastal flooding and erosion	Loss of inter-tidal habitats due to coastal squeeze. This is very likely in urban coastal locations, where natural processes of coastal change are often impeded by hard sea defences. Erosion and loss of sediments in areas defended by hard structures can have knock-on effects in other locations as natural processes of sediment transportation are disrupted. Potential changes to fresh water coastal habitats due to inundation and saline intrusion.	Urban areas at the coast or located on tidal rivers will be at greater risk of flooding from extreme events e.g. storm surges if adaptation measures are not taken. This will lead to knock on impacts for communities living in affected areas. Saline inundation of potable ground water used for human consumption, industry and crop irrigation
Increased frequency of extreme events.	Drought, flooding, storms, coastal storm surges	Increased stress for sensitive species, leading to reduced breeding success and greater susceptibility to other pressures. Increased individual mortality e.g. by drowning, desiccation, and wind throw. Potential changes to fresh water coastal habitats due to inundation and saline intrusion.	Extreme events have the potential to cause death and injury, and can disrupt lives; and those affected can experience mental health problems. These impacts are likely to intensify as the severity and frequency of extreme events increases, and recovery times between disruption events is reduced.

How can green infrastructure assist adaptation to climate change?

The following sections examine the main climate change impacts on urban areas and show how different approaches to green infrastructure provision can help address these impacts, while also delivering benefits for biodiversity, recreation and landscape enhancement. These sections cover:

- Flooding
- Drought
- The Urban Heat Island effect
- Biodiversity enhancement
- Coastal flooding
- Conservation of soil function

Flooding

The issue

Climate change projections show that while the total amount of annual precipitation may stay roughly the same, its seasonal distribution may change and precipitation events may become more intense. Increases in extreme precipitation events, coupled with large areas of hard, non-permeable surfaces in urban areas and degraded catchment habitats upstream, will lead to increased water run-off and reduced infiltration to groundwater stores. In addition, increases in peak flows and reduced lag times in rivers can lead to flooding, with associated erosion and pollution. Heavy metals such as cadmium, chromium, copper, lead and zinc can be washed off road surfaces and into natural water bodies, if well designed detention basins or retention ponds are not present (Barbosa & Hvitved-Jacobsen, 1999). Along with nutrient pollution from overloaded sewer networks, this will further degrade urban ecosystems.

What can green infrastructure do?

Well-designed green infrastructure can help provide flood management services as an adaptation response to climate change. This includes reconnecting rivers with their floodplains, reducing run-off, slowing the flow of floodwaters, directing and storing water temporarily so that it causes less damage, filtering water to remove pollutants, and modifying infiltration. It can also help to improve the quality of water flowing into watercourses and underground aquifers, and provide wider biodiversity, landscape and amenity benefits. Specific elements of green infrastructure that can address the increased risk of flooding expected as a result of climate change include:

- Sustainable drainage systems (SuDS).
- Green roofs.
- Wetlands.
- Street trees, parks and gardens.

Sustainable Drainage Systems

SuDS aim to intercept and manage water run-off, so as to reduce flood risks, both within urban areas and further downstream. They can also help to remove contaminants from run-off. They generally aim to mimic natural processes by intercepting water close to its source and allowing it to infiltrate into the ground, or be retained in storage areas. SuDS can use a range of techniques to deliver water harvesting, infiltration, conveyance, storage, and treatment. Components of SuDS can include artificially created wetlands and retention ponds, vegetation-based systems such as reed beds, permeable surfaces, dry ponds, infiltration trenches, soakaways and rain gardens (see table below). They can be particularly important if created in areas with a high number of minor developments (such as paved impermeable driveways) where the cumulative impact of such developments has not been considered. SuDS can be incorporated into a wide range of new development schemes, and can also be successfully retrofitted to existing developments.

Some SuDS, such as water retention ponds and wetlands, can also improve water quality by acting as filters and trapping polluting particulates which would otherwise enter urban streams and harm biodiversity (Charlesworth 2003). Different SuDS components are capable of offering a range of different treatment functions and service levels, depending on their design.

Example SuDS components and purposes	
Wetlands	Shallow ponds and wetlands, including reed beds, covered with aquatic vegetation, that provide storm attenuation, sediment settlement, and pollutant removal.
Swales	Vegetated drainage channels or troughs with a shallow gradient to reduce flows. They provide storage and/or conveyance of surface water, infiltration and settlement of particulate pollutants.
Retention ponds	Ponds near to hard surfaces that provide storm attenuation, sediment settlement and pollutant removal
Trees	Trees can help surface water management through processes of transpiration, interception, increased filtration and phytoremediation[41].
Permeable pavements	Pavements and hard surfaces that allow infiltration or temporary water storage prior to discharge.
Infiltration trenches	Shallow trenches filled with stone/rubble located to receive lateral flow from an adjacent impermeable surface; they create temporary storage, filtration, and infiltration if unlined.
Soakaways	Lined or loose-filled excavated pits that provide better infiltration, storm-water attenuation and groundwater recharge.
Rain gardens or filter strips	Vegetated strips which accept runoff as overland sheet flow from upstream development, and are located between a hard surface and a receiving component. They provide vegetative filtering, settlement of particulate pollutants and infiltration.
Green roofs	A roof of a building that is partially or completely covered with vegetation and a growing medium, which can reduce run-off and attenuate peak flows.
Bioretention	Shallow, depressed landscaped areas, which use engineered soils and enhanced vegetation to filter pollution and reduce runoff; for example, planted areas in car parks.
Detention basins or dry ponds	Excavated areas close to rivers, streams and lakes used to intercept and store water for a limited period of time and protect against flooding.
Geocellular systems or below ground storage/ infiltration	It is generally recommended to handle run-off at surface, but at some sites this is not possible, so modular plastic systems with a high void ratio can be inserted, for example under street tree trenches, to help capture and slowly release run-off.

41 The use of plants to remove pollutants from soil, air or water.

Wetland restoration case study:

Beam Parklands, biodiverse community flood risk management.

Beam Parklands is a multifunctional wetland park in East London that opened in 2011. It sits on the floodplain of the River Beam, a tributary of the River Thames that forms the boundary between the London Boroughs of Barking and Dagenham, and Havering.

Single issue green infrastructure vs. multifunctional flood storage at Beam Parklands. © S.Davenport

Prior to the creation of Beam Parklands, the site had functioned as an Environment Agency flood storage reservoir, protecting local homes, schools and businesses, including Barking Power Station. However, during upgrade works a more ambitious flood protection scheme was conceived. The exceptionally biodiverse but under-used site was redesigned and connected to other areas, changing it from a single function piece of green infrastructure to a much more multifunctional area of green space that contributes to the **All London Green Grid**. The local community was involved from the beginning of the project, ensuring they benefit from the recreational provision as well as the flood storage function.

Green roofs

A green roof is a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproof membrane. It may also include additional layers such as a root barrier and drainage and irrigation systems. Green roofs are loosely categorised by the type of vegetation they support, from 'intensive' roofs used for food growing and formal green spaces, through to 'extensive' roofs which are more naturalistic and can support a range of wildflowers.

Green roofs serve several purposes, such as absorbing rainwater, providing insulation, creating a habitat for wildlife, providing an aesthetically pleasing environment, and helping to lower urban air temperatures (The GRO Green Roof Code 2014). Green roofs can also be combined with solar panels to enhance the performance of the panels (Chemisana & Lamnatou 2014; Tomazin 2016).

Rain falling on conventional roofs moves rapidly towards drains. Green roofs use the natural functions of plants to slow down run-off and retain water in the roof's substrate before evaporating it back into the atmosphere. By retaining and slowing the release of water in periods of heavy rainfall, green roofs help to reduce peak flows. They can also retain and treat contaminants that are introduced to the surface either as dust or suspended in rainwater (Living Roofs Code of Practice) and can help to neutralise acidic rainwater (Berndtsson 2010). Roofs that are designed to provide heterogeneous wildlife habitat perform as well or better at water attenuation than less diverse vegetated roofs, while supporting greater biodiversity (Connop & Nash 2016).

Wetlands

Establishing wetlands, and riparian and floodplain woodlands, can help to reduce peak flood volumes and provide areas where rivers can flood without causing damage. There may be significant opportunities for wetland creation in rural areas that will reduce the effect of flooding on settlements. In urban areas, existing green infrastructure within flood zones can be safeguarded to help manage riverine flooding, and artificially constrained waterways can be restored to a more natural state.

Restoring floodplains, widening river corridors and setting back flood banks can provide space for excess water to be redirected and stored. This can help to re-establish a more natural flood management process upstream, thereby reducing flood risk for settlements and infrastructure downstream.

The restoration of floodplains also helps to reduce water pollution by metabolising pollutants, and can contribute to managing water availability by storing water in periods of heavy rainfall, then releasing it in dryer periods. This can help support river flows and water availability in summer by recharging aquifers and ground water.

Larger flood plain restoration projects that enable greater floodwater storage are very important. However, in the urban context, a matrix of different SuDS for rainwater run-off retention can be very effective by applying the same fundamental principles of intercepting flows and improving infiltration at a more localised scale.

The physical and functional connections between habitats made by green infrastructure can provide routes for species movement and can help improve the resilience of native biodiversity. Canals and rivers, alongside flood storage areas, can support this function. In urban areas they can play an important role in providing a refuge for species that may have lost their original, natural habitat.

Mayesbrook Park, London

The intention at Mayesbrook Park was to update 50 year old flood management infrastructure in an area of East London suffering from localised flooding and lack of natural green space. The project used a more 'nature based' approach to flood management, while providing a multifunctional landscape that is more resilient to climate change for people and wildlife. The works restored natural meanders to the Mayes Brook, through the creation of 500 m of new sinuous water channels, which help to slow high flows and improve habitat diversity, while 450 m of re-graded banks help to increase the capacity of the river and improve the riverside habitat. The work has created 1.5 ha of new floodplain and provided areas of wetland, meadow and woodland habitat.


Before


During works


The restored river at Mayesbrook Park

An ecosystem services assessment helped build the case for investment showing the integrated urban river restoration provides a long-term return to society of at least £7 for every £1 spent. Extensive public consultation helped the partners address local concerns and the area is now a well-loved and used urban greenspace. There are future plans to link this park with another nearby park to provide connections for people and nature.

Street trees, parks and gardens
Street trees, in association with sub-surface retention systems (areas under streets and pavements where water can be collected and used by street trees or passed slowly in to the sewerage system) can help manage surface water and urban diffuse pollution, as shown by the **Howard Street** experiment in Salford. Parks and gardens are also important for climate change adaptation, and green elements associated with hard infrastructure, e.g. road verges, also provide important support to managing flood risks and pollution.

The Forestry Commission's **i-tree Eco Tool** assessment of London found that, among other ecosystem services, London's 'urban forest' (which consists of nearly 8.5 million individual trees with a leaf area of some 1047 km^2) currently prevents 3,414,000 cubic metres of run-off per year and provides £2.8 million worth of flood alleviation benefits (Treeconomics 2015).

Natural Flood Risk Management Evidence Base

The Environment Agency (2017) has published **Working with Natural Processes – the evidence behind Natural Flood Management** which synthesises the evidence base for natural flood risk management. It includes an evidence directory, maps and supporting guides to help flood risk managers to access up-to-date information and to fully understand the potential benefits.

Drought

The issue

Higher temperatures and reduced summer rainfall are likely to lead to more frequent periods of drought and pressures on existing water resources.

What can green infrastructure do?

Green infrastructure has the potential to:

- Help retain water.
- Increase biodiversity survival in times of heat and water stress.
- Provide shade and cooling.
- Be incorporated into rainwater harvesting systems to improve water use efficiency and reduce demand on natural sources.

Well-designed green infrastructure can help vulnerable species to survive in periods of drought. For example, a green space designed with a matrix of habitats, species diversity, and drought tolerant planting will be more likely to survive drought and provide cool and shaded refuges for species during hot, dry periods. Water bodies can provide much needed water for animals and people (e.g. recreation) in times of drought and provide a cooling effect in the local area. Furthermore, green infrastructure such as parks, with deep soil bases, can act as natural water reserves, with trees helping to increase the infiltration of water into the soil.

However, green infrastructure can be vulnerable to drought itself, which can affect its functionality and biodiversity (Gill *et al* 2013; Speak *et al* 2013). It is also important to note that if large amounts of artificially provided water are required to keep green infrastructure functioning, it could cause an added water stress. Therefore, the right design and scale in the right place is required, in order to provide green infrastructure that is sustainable under drought conditions. Integrating water capture and retention techniques, suitable planting and appropriate design can help ensure this.

The Urban Heat Island effect

The issue

The urban heat island effect is what causes urban areas to be warmer than the surrounding countryside. In contrast to rural areas, where night-time relief from high daytime temperatures occurs as heat is lost to the sky, the urban environment traps and stores more heat, which is re-emitted overnight, keeping temperatures higher than the surrounding countryside (Smith & Levermore 2008). Areas with limited vegetation, hard artificial surfaces and anthropogenic heat sources all contribute to this, as do high buildings and complex topography, which can restrict air flows and trap hot air (Brown 2015). In the UK, temperature differences between cities and rural areas can be more than 70°C (Smith & Levermore 2008), and increases in mean air temperatures and more frequent heatwaves mean that heat related issues in built-up areas are likely to become more of a problem in the future (Hathway & Sharples 2012; **UK Climate Change Risk Assessment Evidence Report 2017**).

What can green infrastructure do?

Green infrastructure can help to reduce ambient temperatures in urban areas by providing shade from the sun, and natural cooling as a result of evapotranspiration. This can be achieved by creating areas of green and blue space and tree planting, and by installing green roofs and walls. These approaches are likely to become more important in built up areas as average temperatures rise and periods of extreme high temperatures become more frequent.

Green and blue spaces and tree planting

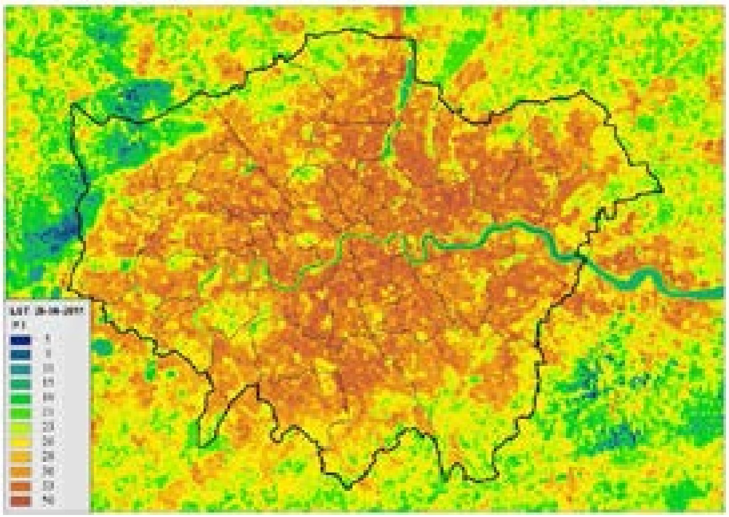
Green spaces create cooler microclimates through evapotranspiration; when water evaporates from leaves and the earth's surface, energy is absorbed from the air, creating a cooling effect. The shade provided by mature trees on streets and in parks and gardens reduces temperatures locally and can shield building facades and street surfaces from the sun. The amount of energy stored by the built fabric during the day is therefore reduced, and so the urban heat island effect is reduced. Gill *et al* (2007) performed a study on the cooling effect of green spaces in Manchester using modelling techniques and based on the UK Climate Projections 2002. They found that adding 10% green cover to areas with little green space, such as town centres and high-density residential areas would reduce maximum surface temperatures by 0.7-1.20°C (low emissions-high emissions scenarios, 2080s). If the green space was not added, the surface temperature would increase by 1.7-3.70°C (low emissions-high emissions scenarios, 2080s). In contrast, removing 10% of existing green cover in town centres would lead to an increase in temperature of 7-8.20°C by 2080 under the low-high emissions scenarios (all changes are in relation to the 1961-1990 baseline).

Water bodies complement the role of trees and green space by further moderating surface temperatures through evaporative cooling. In drought conditions, when the cooling effects of vegetation in green spaces are impaired, the role of urban water becomes more pronounced.

In clear sky conditions, shade provides an important cooling effect for individuals, and broad leaved deciduous trees provide the greatest benefit. They reduce not only the solar radiation felt directly by people, but also the amount of radiation absorbed by the ground, which would otherwise be re-emitted. It is therefore important to plan ahead to enhance and replace existing stocks and allow trees to grow to maturity. Leafy shrubs and hedges also further reduce thermal re-emission from the ground compared to lawn surfaces. This highlights the need to provide a variety of vegetation in green spaces, which will also generally enhance their biodiversity value.

As well as cooling the air locally, green spaces can also create air movement, causing cooler air to be blown towards surrounding neighbourhoods, creating statistically significant cooler temperatures in these areas too (Brown *et al* 2015). Modelling suggests that green spaces can have a city-wide cooling effect (Gill *et al* 2007).

Green and blue spaces will be most effective in urban areas with sparse existing vegetation, little open space, and high building density. The cooling services of green infrastructure can be particularly significant for vulnerable people during periods of heat stress (**Doick *et al* 2017**). Design should ideally focus on shaded green space. Tree species with dense foliage (high leaf area index) or which produce dappled shade are most useful. The size of the green space is also important. It has been found that green spaces develop a distinctive climatic effect when they are greater than 1 ha in size (von Stülpnagel *et al* 1990), and that a cooling service on calm warm nights within cities with similar climate and characteristics to London may be provided by green spaces of 3–5 ha, situated 100–150 m apart (Vaz Monteiro *et al* 2016).



London, June 2011, Land Surface Temperature. © Arup (2014)

Illustration of green and blue spaces in London
Source: https://maps.london.gov.uk/green-infrastructure/ Open Government Licence v3

The map opposite shows how urban green infrastructure can reduce the urban heat island effect through the cooling effects of evapotranspiration and shade. The map shows the surface temperature of London on the night of 26 June 2011 (in °C). The red areas are hottest and the green, the coolest. The densely built up West End (theatres/shops/tourist attractions) is 8% hotter, at 31 °C, than Richmond Park, a large area of urban green space, which is much cooler at 23 °C. When you overlay the vegetation map of London, it shows a strong correlation between green areas and the lowest temperatures.

Green roofs and walls

Green roofs and walls can provide cooling, flood management, and biodiversity benefits (**Greater London Authority 2008**). They have also been shown to lower ambient temperatures by reducing night-time heat radiation, shielding building materials from the sun, and storing water in substrates, which provides evapotranspirative cooling (Alexandria & Jones 2008). Greening roofs in areas with a high proportion of buildings is an effective strategy to reduce surface temperatures (Gill *et al* 2007). Green roofs can also increase insulation, making buildings more efficient and reducing energy use e.g. helping to reduce the energy use for air-conditioning in buildings in summer and heating in winter (Smith & Levermore 2008; Castleton *et al* 2010).

Green walls work in a similar way to green roofs. They can help reduce the urban heat island effect through the interception of light and heat radiation which would otherwise be largely absorbed and converted to heat by building surfaces and then radiated back into the surrounding streetscape. They can also play a role in intercepting and temporarily holding water during rainstorms, in the same way that green roofs do. They also trap dust and filter out harmful pollutants in the atmosphere, as well as helping tackle noise pollution both inside and outside of buildings.

When modelling the cooling effects of green roofs and walls in the spaces between buildings, Jones & Alexandri (2008) found that air and surface temperatures lower significantly when walls and roofs are covered with vegetation. Green roofs act as a constant heat sink through evaporative heat transfer. They also absorb less radiation, which means less heat is absorbed by buildings in the day, and less is re-emitted at night.

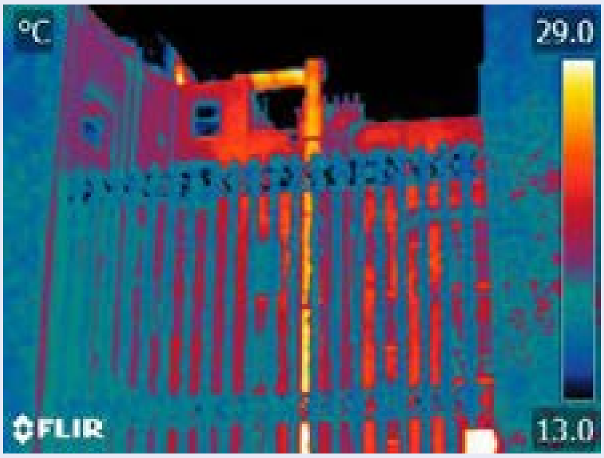
Green roof at Canary Wharf, London. © Natural England/Sarah Taylor

Victoria Business Improvement District (BID), London

The objective here is to retrofit the area of the Victoria BID in Central London with green infrastructure to deliver a range of ecosystem services which underpin economic growth. A BID is a geographically defined area in which businesses make financial contributions to be spent in the area on projects determined by the local business community. The Victoria BID wanted to use natural environment features and biodiversity to create a sense of place and identity, to provide localised adaptation to climate change, and to be an exemplar green infrastructure project in a highly developed area. A baseline green infrastructure audit found that most of the potential for green infrastructure delivery was at roof level. Roofs were assessed to establish their potential to support a range of green roof types, and a plan was developed to identify the best opportunities and to help prioritise approaches to building owners. If the mapped potential for green roofs is delivered in this area, the green cover in Victoria would increase by 80% and 25 hectares of green space would be created, providing increased wildlife habitat and helping to reduce surface water run-off.

The Rubens Green wall

The Rubens Green Wall covers 350 m2 and comprises 10,000 plants, which provide a range of biodiversity, cooling, noise reduction and air pollution benefits. It also incorporates a rainwater attenuation tank and irrigation system to distribute the collected rainwater to the plants. The location was highlighted through the Victoria BID green infrastructure audit. The thermal images below illustrate the cooling properties of the wall.



Thermal Image of green wall on the Rubens Hotel in Victoria. © Thomas Chung, University of Reading/Forest Research

Retro-fitted green wall on the Rubens Hotel in Victoria. © Natural England/Sarah Taylor

Biodiversity enhancement

The issue

Biodiversity is subject to a range of climate change related impacts, as discussed elsewhere in this manual. These include population range shifts, changes in the timing of seasonal events and the interactions between species, vulnerability to extreme weather events, and indirect impacts from our responses to climate change.

Our traditional framework for valuing habitats and sites may not always work in an urban context, and it might be more useful to think of urban areas as having their own characteristic suite of habitats and species, reflecting the physical environment and cultural history of developed areas. In some instances, urban areas may be more biodiverse than surrounding agricultural land. It is not just large open spaces that are important; the matrix of smaller bits of habitat and green space can also be valuable for nature conservation in a changing climate, and the potential for green infrastructure within urban areas to deliver benefits for both nature and people should be recognised.

What can green infrastructure do?

Good quality and well planned green infrastructure can contribute to our network of ecologically rich sites, and has the potential to help nature to adapt to climate change by:

- Providing new areas of valuable habitat.
- Reinstating natural functions such as water and nutrient cycling.
- Providing increased connectivity between fragmented areas of habitat.
- Allowing people to access and enjoy nature and learn about the importance of the natural environment.

These biodiversity benefits can often be delivered in combination with flood and heat regulation. Examples of green infrastructure that benefit biodiversity include:

- Conventional green spaces and wetlands, which provide semi-natural features and can increase habitat size and connectivity;
- Soft Infrastructure, including green roofs and walls, gardens, and flood alleviation features.

Conventional green spaces

These include informal areas of open space, parks and wetlands that contain areas of semi-natural habitat, as well as more formal nature reserves and other designated sites. Such areas will often provide a range of ecosystem services, as previously discussed, as well as providing valuable wildlife habitat, and will be vulnerable to the impacts of climate change as well as helping provide nature-based solutions to some of the impacts likely to be felt.

When creating or improving an area of green space it is important to consider how the effectiveness of any biodiversity enhancements could be influenced by the surrounding area. For example, there may be a risk that storm water runoff could flood the habitat and carry pollutants into sensitive habitats, or that invasive species could colonise from nearby gardens. Green infrastructure can be considered to be an arrangement of semi-natural features that work best when connected and functioning in a network that extends through and across the urban area and out into peri-urban and rural areas.

The principles of design and scale for green infrastructure are discussed further later in this section.

Soft infrastructure
Green infrastructure that is designed to provide another service to urban areas, such as floodwater attenuation or urban cooling, can also be designed to enhance biodiversity. For example, it can be designed to maximise the benefits for known local wildlife or species that struggle in urban situations, or to provide greater permeability between habitats within an otherwise hostile environment. However, in order to provide biodiversity benefits, this needs to be considered and incorporated into the design at an early stage, or opportunities to enhance biodiversity could be missed.

The potential for any form of green infrastructure to enhance biodiversity should be a primary design consideration. Creating a range of habitat and vegetation types, ensuring variation in topography and vegetation height, and providing specific features such as areas of wetland and woodland will all help to maximise biodiversity potential. More information about this can be found in Natural England's guide series on the **Mosaic Approach** (Natural England 2017).

Green roofs can provide habitat for many invertebrates, including those listed as rare or scarce (Kadas 2006). It is also possible that green roofs, if designed and located well, may also provide new links in an often fragmented network of habitats, thereby facilitating movement and dispersal of wildlife through urban areas. This is more likely to be beneficial for mobile groups such as flying insects and birds, but more research is required to assess their contribution to connectivity (Williams *et al* 2014). As species' ranges change in response to climate, green roofs may provide important stepping stones to aid this movement. Green roofs can also provide new habitat in areas which are currently lacking in wildlife interest.

Within cities, some of the most biodiverse areas can be previously developed brownfield sites, which are often at risk of redevelopment. The London Wildlife Trust has estimated that about a quarter of the city's wildlife sites are wholly or partly brownfield in character and if they were redeveloped it could mean a significant loss of urban biodiversity. They note that some London brownfield sites have already been so damaged or destroyed that they can no longer support the wildlife they were noted for (London Wildlife Trust 2002). The London Wildlife Trust also highlights that rapid growth in London puts considerable direct and indirect pressure on the locally important wildlife sites in the city (London Wildlife Trust 2015).

Green roofs can provide some compensation for lost brownfield habitats. For example, there is good evidence that the black redstart *Phoenicurus ochruros*, which is rare in the UK, uses extensive green roofs as nesting sites (Frith, Sinnadurai & Gedge undated). Designing green roofs that include varying substrate depths and drainage regimes creates a mosaic of habitats and can help the green roof avoid the negative impacts of drought that can be found on roofs with shallow substrates, and can facilitate colonisation by a more diverse flora and fauna (Brenneissen 2006). At the Queen Elizabeth Olympic Park in London, bio-solar roofs, which combine biodiversity benefits and photovoltaic energy systems, supported 92 plant species, with a variety of vegetation structure, and many invertebrate species of conservation concern (Nash *et al* 2015). Appropriate design and location is crucial in order to realise these benefits.

A bee's eye view of sustainable living (Davenport, in Dales, Doran & McGregor 2016)

Barking Riverside in East London is one of the largest redevelopment sites in the country. It covers 180 hectares and the site is home to protected and notable species, including rare and scarce invertebrates that are often found on the early successional habitat mosaics of brownfield sites. The redevelopment will deliver nearly 11,000 new homes, but it will also weave in green infrastructure and recognise the ecosystem services the site provides, including conserving the site's valuable biodiversity, retaining 40% of the site as green space, and developing a Sustainable Urban Drainage Systems plan.

Wetland habitats created on green roofs. © Caroline Nash

Research was conducted to test how a development can be designed to deliver truly multi-functional green infrastructure, including an ecologically led approach to green roof design. New roofs on site incorporate ephemeral wetland habitats that are typical of high quality brownfield habitats, and a niche often missing from green roof designs used to compensate for the loss of biodiverse brownfield habitats. The work also trialled a range of terrestrial landscaping options designed to incorporate ecological niches required by the species at Barking.

Monitoring showed the habitats were quickly colonised by notable invertebrate species, such as the shrill carder bee, and species diversity was found to be much greater on the ecologically designed areas than the traditionally landscaped control areas. The aspiration is for Barking Riverside to become a benchmark for sustainable design and the best way to deliver multifunctional green infrastructure.

For more detail see Natural England's **Chief Scientists Report 2015 - 2016** pp. 51-52

Gardens can provide a valuable refuge from the impacts of climate change for urban wildlife, by providing pockets of vegetation and shade, and can be particularly important for drought sensitive animals such as amphibians. Their usefulness will depend on their design and the way they are managed, and to be most beneficial to wildlife, gardens should provide a good range of food sources, water, shelter and nesting sites. As with other types of green infrastructure, if designed well, urban gardens can provide a valuable addition to the mosaic of green and blue spaces that contribute to climate change adaptation within urban areas.

Coastal flooding

The issue

Coastal flooding is likely to become more frequent as sea levels rise, and will impact on the people, buildings, infrastructure and wildlife of coastal settlements. Where inter-tidal habitats, which would otherwise provide a degree of flood protection, are constrained by artificial structures, leading to increased erosion and coastal squeeze, the ability to mitigate flooding of built up areas inland will be reduced.

What can green infrastructure do?

Just as various forms of green infrastructure can help protect urban areas from fluvial flooding, green infrastructure at the coast can help to address coastal flooding. At the coast, the term green infrastructure can be applied to both naturally occurring habitats, such as sand dunes and salt marshes, which can provide a buffer between coastal settlements and the sea, and to designed structures such as sea defences that may incorporate elements of green infrastructure. Specific elements of green infrastructure that may address coastal flooding and erosion include restoration of coastal and wetland habitats, managed realignment to create new areas of coastal habitat, and the incorporation of green infrastructure elements within hard sea defences.

Green infrastructure at the Coast

Actions at the coast that can help provide protection and adaptation for coastal settlements include protecting, enhancing and increasing coastal wetlands, which provide natural storage areas and can accommodate coastal floodwaters, potentially preventing other areas from flooding. In addition, dune systems and salt marshes provide a natural buffer against coastal flooding, by helping to dissipate wave energy and thus reduce erosion. Green infrastructure can also be incorporated into hard coastal defences, where evidence suggests it can enhance the performance of a seawall, as well as providing habitat niches and features for biodiversity (CIRIA 2014). Where engineered sea defences are still required, this hybrid approach, using both green and grey infrastructure, can provide effective and affordable options and often have positive additional benefits (The Royal Society 2014).

Green infrastructure interventions to manage coastal flooding will, to a large extent, involve safeguarding and enhancing existing habitats, which provide a natural buffer from the sea and provide space to enable habitats to roll back naturally. Creating new habitats, for example through managed realignment, will be possible, but these will generally take time to function as well as established habitats. However, in many instances, the service provided by green infrastructure in managing coastal flooding could be enhanced by the creation of areas of marsh and other wetland habitats, alongside other multifunctional green spaces. This can help to relieve the problems of coastal squeeze and create a more natural coastline, which is better able to absorb the sea's energy and withstand major flood events, while providing wider recreational and biodiversity benefits.

Managed realignment at Freiston Shore, Lincolnshire

There is a range of examples of managed realignment providing ecosystem-based adaptation alongside hard sea defences to reduce vulnerability to coastal flooding. Freiston Shore, Lincolnshire, was selected for managed realignment in 2002, because erosion rates at the base of the sea wall were increasing, leading to escalating repair and maintenance costs. The measures at Freiston Shore were found to be very cost effective; the wave attenuation function of the saltmarsh vegetation is predicted to decrease the overall costs of the sea defence structures. The Environment Agency estimated that an 80 m wide saltmarsh margin could reduce a sea defence height from 12m to 3m, with a financial saving greater than an order of magnitude (Colls, Ash & Ikkala 2009). There are many benefits of the realignment at this **RSPB reserve**, as it attracts thousands of wetland birds throughout the year and provides a recreation resource.

New York City Green Infrastructure Plan, (Mayor of New York City 2010)

The majority of New York City's key infrastructure lies less than 3 metres above sea level. This highlighted a problem during extensive coastal flooding by Hurricane Sandy. The frequency of extreme weather such as hurricanes and storms is likely to increase with climate change. The city published its Sustainable Storm Water Management Plan in 2008 and its Green Infrastructure plan in 2010 to address these issues. Plans include increased vegetated areas along the coast and permeable pavement material to absorb water and slow run off times. The city already uses beach nourishment and restoration of sand dunes to combat flooding. See New York Green Infrastructure Plan for more information.

Conservation of soil function

The issue

There is growing awareness of the role soils play in providing a range of ecosystem services and supporting human activities, as recognised by the Millennium Ecosystem Assessment and the UK National Ecosystem Assessment. Soils form slowly, taking on average 100 years to make 1 cm of topsoil, and should therefore be considered a non-renewable resource (Environmental Audit Committee 2016). Despite this understanding, their use and mismanagement can result in the degradation of their physical, chemical and biological properties, potentially affecting their function and the services they provide. By taking into account the effect of soil degradation on soil properties and the ecosystem services they provide, Graves *et al* (2015) estimated the current total cost of soil degradation in England and Wales at between £0.9 billion and £1.2 billion. Despite these high estimates, there are significant evidence gaps concerning degradation of urban soil, particularly in association with urban green space and the sealing of soil under impermeable materials (Graves *et al* 2015).

Climate change is expected to have an impact on soils (UK Climate Change Risk Assessment 2017), with both direct and indirect effects on soil properties and processes. The interaction between these are complex, but the balance between soil temperature and moisture exerts a significant control, causing soil processes, properties and functions to be sensitive to changes in climatic conditions. While there are still significant evidence gaps in this area, it is clear that effective climate change adaptation methods require an understanding of the multifunctional role soils can play.

What can green infrastructure do?

In all locations, good soil management is important to ensure soils are resilient in the face of climate change, in order for them to provide climate change adaptation benefits through water regulation, urban cooling and drought management. Soils are the foundation for many of the ecological processes discussed in this manual, such as habitat development, biogeochemical cycling, and the life cycles of many organisms. Green infrastructure can contribute to soil conservation, and thereby ecosystem services and climate change adaptation, in a number of ways:

- Preventing soil erosion.
- Creating and maintaining permeable surfaces.
- Engineered soils.

Preventing soil erosion
While erosion is a natural process, it can be exacerbated by cultivation, deforestation and pressures from overgrazing. Future climate change projections could also influence erosional processes due to predicted increases in the frequency and intensity of rainfall events (UK Climate Change Risk Assessment 2017). *In situ* soil loss affects agricultural productivity and damages semi-natural habitats, but severe impacts of degraded soils are often felt 'off-site' (Graves *et al* 2015). The transport of sediment can damage downstream infrastructure, such as roads, waterways and drains, and habitats, such as wetlands, and can carry nutrients, depositing them in areas of sensitive biodiversity.

Green infrastructure can be implemented and enhanced to target and reduce soil erosion where there is a risk and where climate change may exacerbate this risk. This is especially important in upland areas, on slopes, and along the banks and floodplains of streams and rivers or close to transport infrastructure. Woodland planting can reduce soil erosion at source, litter and roots acts to keep soils in place and limit the delivery of sediment to watercourses, protect river banks from erosion and encourage sediment deposition within the floodplain. Vegetation can also reduce nutrient loss via uptake by plants and trapping soil particulates (Broadmeadow & Nisbet 2010). While the impact on soils from climate change and land use interactions are complex and require further research, it is widely recognised that measures to maintain vegetation cover and soil structure is essential to protect soils from future erosional pressures (UK Climate Change Risk Assessment 2017).

Creating and maintaining permeable surfaces
In England, urban areas account for over a tenth of the national land surface (Davies *et al* 2011), and for much of this land the soil is sealed under hard, impermeable surfaces. Sealing soils leads to a serious loss of soil functions and the ecosystem services they provide. This includes restricting plant growth, limiting the cycling and storage of nutrients and water, and acting as a barrier at the soil-atmosphere interface, restricting gaseous exchange. The impermeable nature of most construction materials, meaning that water can no longer infiltrate the soil, often leads to severe localised flooding. Utilising woodland and other vegetation increases surface roughness, slowing run-off flow and increasing percolation into the soils, delivering not just a reduction in peak flow rates but other benefits such as retention of nutrients, trapping of pollutants and recharge of ground waters (Demuzere *et al* 2014; Spatari, Yu & Montalto 2011).

These benefits rely on soil properties to deliver effective flood management, and are further dependent on suitable siting in the urban landscape. Alongside the floodplains, SuDS and wetlands discussed elsewhere, networks of vegetated corridors and patches containing soils with a high infiltration capacity can influence the timing and quantity of run-off. In new developments and where it is impractical to replace sealed surfaces with vegetated areas, then porous paving materials could be considered. These materials significantly reduce run- off rates, increase infiltration, and reconnect urban surfaces with the hydrological benefits soils can provide (Rawlins *et al* 2013).

As discussed above, areas with extensive sealed surfaces also generally absorb more solar radiation, exacerbating the urban heat island effect (Rawlins *et al* 2013). Vegetation and green roofs can contribute significantly to reducing the impact of this by cooling the surrounding air via evapotranspiration (Demuzere *et al* 2014). However, evapotranspiration is limited by soil moisture, and rates decrease during dry periods of weather. By considering the water retention capacity of local soils and methods to maintain soil moisture levels, such as irrigation, the effectiveness of this method can be increased, as well as providing a cooling effect via evaporation from the soil itself.

Engineered soils

Soils are living, breathing systems that take millennia to form and, as such, priority should be given to preserving undisturbed sites to maintain natural processes. However, soils underpin much of the green infrastructure described in this chapter and in some cases their properties can be modified to increase their green infrastructure benefits. Engineered soils are soils that have been designed or modified to perform functions required for a specific location. These engineered soils can then be used in rain gardens, green roofs and bioswales to support the local soils in the services they provide. The core properties of engineered soil in green infrastructure are (Soil Science Society of America 2017):

- Steady infiltration of water – slowly enough to filter and adsorb contaminants, but at a rate fast enough to prevent flooding.
- Resist compaction – soil compaction can reduce infiltration rates leading to surface water retention
- Maintain nutrients and moisture to support plant communities and wider biodiversity benefits.

Engineered soils can also provide other benefits besides water management. Studies led by Newcastle University have demonstrated that such soils can sequester significant amounts of atmospheric carbon when calcium and magnesium silicates are present on urban brownfield sites due to demolition activity (e.g. cement and concrete from demolished buildings) (Washbourne, Renforth & Manning 2012). These react with atmospheric carbon dioxide, channelled underground by plant communities, forming stable, long-term carbonates. While further research is necessary, the growth and regeneration of urban areas means these areas could also act as carbon capture sites, mitigating climate change as well as providing adaptation benefits.

Engineered soils - Omaha, Nebraska, USA

In the late 1800s, and inspired by European cities, the city of Omaha, Nebraska, employed the landscape architect Horace Cleveland to design a network of parks and tree-lined boulevards for residents to enjoy. These historic sites are now being explored to help manage storm water run-off from hard-engineered surfaces, through trialling the use of engineered soils within the green infrastructure network. The approach taken is to consider the targeted use of engineered soil trenches within areas of undisturbed soils. This increases infiltration and manages storm flow where a risk has been identified, but preserves the structure and function of local soils and reduces costs (Fisher 2015).

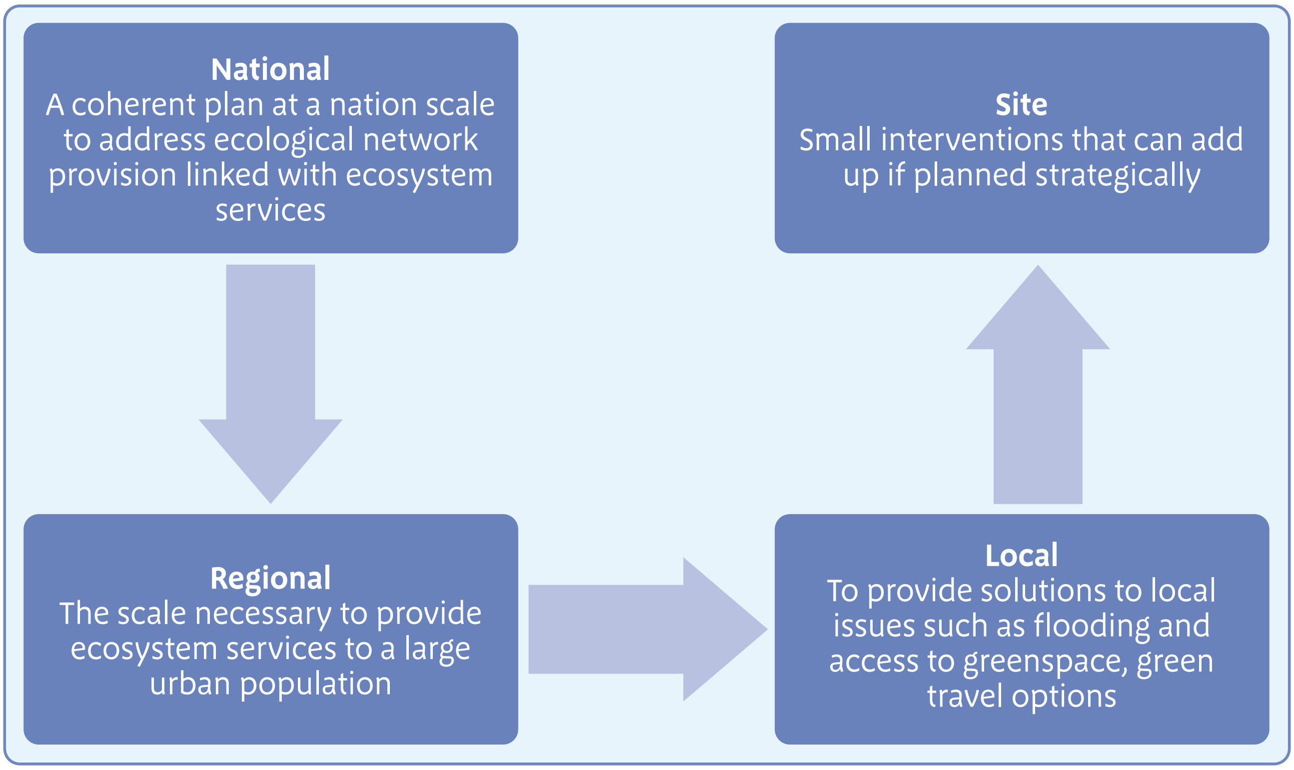
Scale and design of green infrastructure

When planning any green infrastructure in urban areas, the issues of scale, design and multi-functionality are crucial. These are considered below. More information on planning green infrastructure improvements is contained in Natural England's **Green Infrastructure Guidance** (Natural England NE176 2009).

Scale

Green infrastructure can be planned at a range of scales, from regional to district and local. In order to maximise the benefits and effectiveness of such planning, these plans should, ideally, be 'nested' so as to support each other (see diagram). In this way, regional plans might address more widespread issues and environmental features that cross administrative boundaries, whereas more local plans can provide the evidence base and policy framework to support more local green infrastructure delivery.

Green infrastructure planning at a regional scale can consider large-scale landscape connectivity and address the provision of ecosystem services, for example, working at a catchment level to address water provision and flood risk management or contributing to ecological networks to help species adapt to climate change (Lawton *et al* 2010). At a more local scale, particular issues can be addressed, such as localised flooding, re-naturalisation of river channels, and provision of green space for access and biodiversity. Planning can also take place at the site level, and in densely developed areas the cumulative benefit of many small scale individual sites can be significant.



The range of scales at which green infrastructure can be planned.

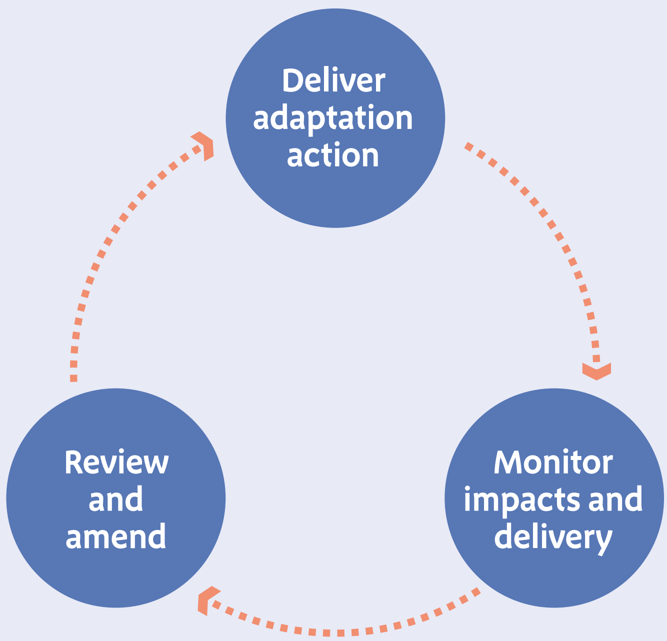
Design
Good design is crucial to ensuring that green infrastructure provision is effective. The process of green infrastructure planning should provide the evidence needed to inform the design of green infrastructure. Such planning will help to identify the range of functions that a specific component of green infrastructure should deliver, based on the requirements of an area, and also provide evidence about the value of existing green infrastructure. Ideally, as most vegetation needs time to mature and reach full effectiveness, green infrastructure should be incorporated into developments at an early stage in order to secure maximum adaptation benefits. However, it can often be successfully retrofitted into existing developments.

Better quality of life for people and integration with the natural environment should be at the heart of any approach to green infrastructure design. The delivery of a combination of green infrastructure assets to provide nature-based climate change adaptation, is vital for sustainable development. As described above, properly designed and located, green infrastructure can help address the vulnerability of both people and wildlife to climate change in urban areas.

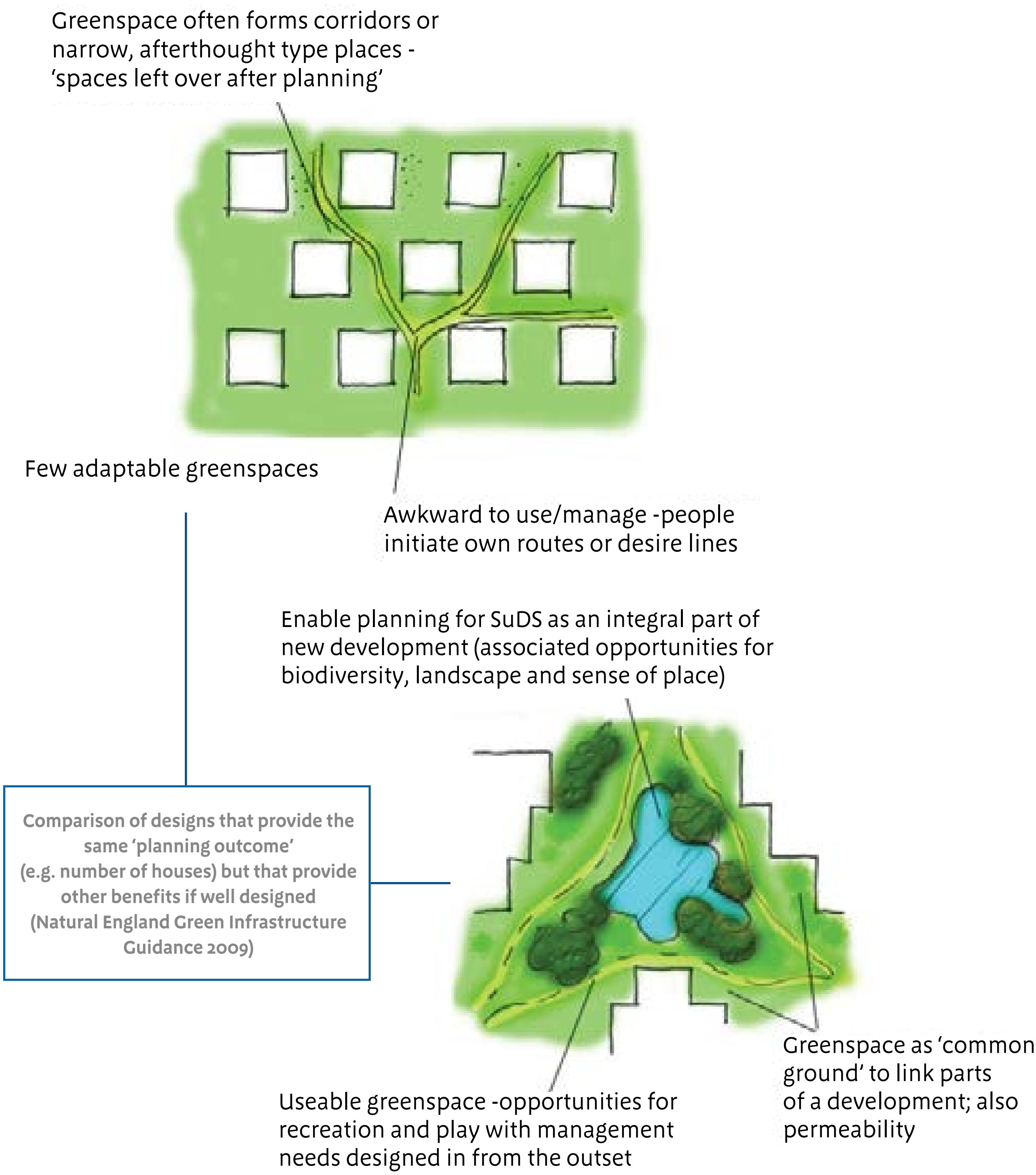
Adaptive management and maintenance

Green infrastructure will often require ongoing management to enable it to continue to function effectively, for example regular dredging of retention ponds. The need for long-term maintenance should be built into any green infrastructure planning and design project. As an example, the **CIRIA SuDS Manual**, which contains detailed information on SuDS design, also covers ongoing maintenance procedures. The need for maintenance, and the ongoing ability to provide it, must be incorporated from the beginning of the green infrastructure and climate change adaptation design period.

Monitoring and maintenance is particularly important for climate change adaptation focused elements of green infrastructure. Changes in climate are not wholly predictable so it is important to ensure climate change impacts and adaptation actions are monitored and reviewed, and if necessary adjusted, to maximise their effectiveness over time.



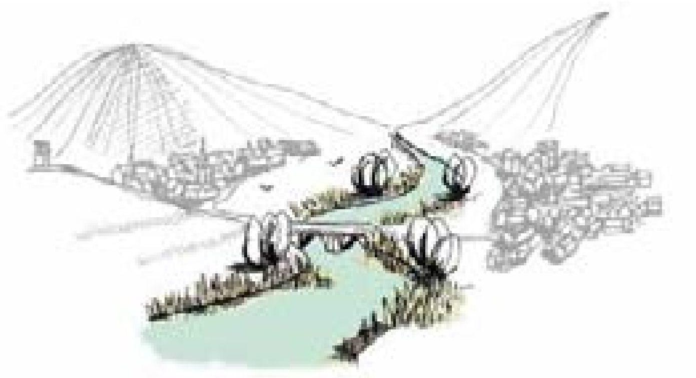
There are many ways in which urban development can be designed. At one end of the spectrum are unimaginative designs that leave little room for open space and the provision of natural services; at the other are more integrated designs which provide a variety of open spaces and deliver a range of ecosystem services, including local climate change adaptation. Stylised examples of these two contrasting approaches are shown below:



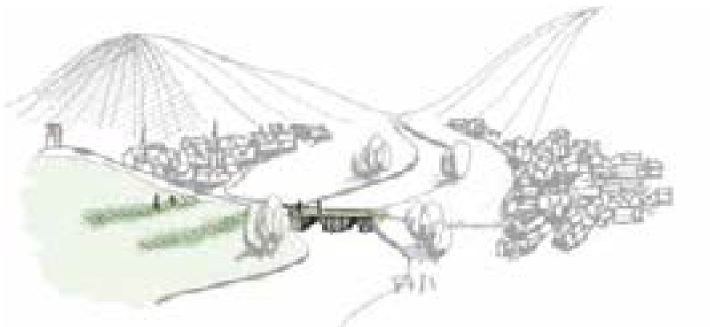
Variety and complexity should be key principles of any green infrastructure design. Heterogeneity in topography, habitat types, and surface roughness and vegetation height etc. are important factors for both biodiversity and ecosystem services such as flood risk management. The concept of surface roughness and habitat heterogeneity is starting to be explored as a flood risk management benefit. A project in Melbourne, Australia (Ossola, Hahs & Livesley 2015) selected a network of urban parks characterised by different proportions of low-complexity and high-complexity wooded patches to measure soil hydrological processes such as water infiltration, water holding capacity, and run-off. The results demonstrate that the fine-scale heterogeneity of urban landscapes had a significant influence on soil hydrology. In particular, water infiltration rates were greatest in patches with more complex and varied habitats, and these types of patches also intercepted and held more storm water than more homogeneous habitats.

The importance of multi-functionality
Multi-functionality – using good design to deliver multiple benefits from a single area - is the cornerstone of effective and sustainable green infrastructure. It has long been recognised that green infrastructure, particularly in busy urban areas, can provide a wide range of benefits in one place. For example, provision of biodiversity conservation can be delivered alongside ecosystem services such as recreation opportunities and green travel options, climate change adaptation such as urban cooling or flood alleviation benefits as well as a providing the mental health benefits of access to more natural spaces.

However, it should not be assumed that all functions are mutually compatible on the same piece of land; they may be mutually supportive, but they can also conflict. For example, an informal recreation area may be able to support increased biodiversity, but a sports pitch requires specific vegetation management to provide its primary function. This underscores the need to view multi-functionality as something that a whole green infrastructure system delivers (appropriate to local evidence of need for specific functions) at a range of scales, rather than a simple concept that applies all functions to the same piece of land. However, green infrastructure systems can be designed so that incompatible functions might operate on the same land but at different times, such as the formal sports field that can also act as a flood storage area in times of high rainfall.


Habitat provision and access to nature


Access, recreation, movement and leisure


Landscape setting and context

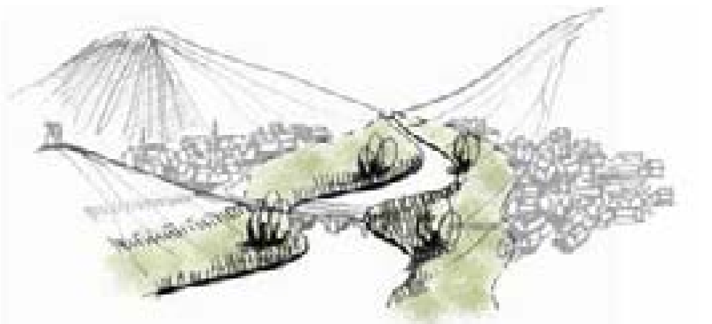

Flood attenuation and water resource management

Illustration of multifunctionality form (Natural England Green Infrastructure Guidance 2009)

Queen Elizabeth Olympic Park

The Queen Elizabeth Olympic Park sits within the Lee Valley Regional Park, which stretches from central London out to the more rural areas of Hertfordshire and Essex. It was designed as the centrepiece of a major regeneration project linked to the London 2012 Olympic and Paralympic Games. As well as providing opportunities for sport and recreation as part of the Olympic legacy, the site has been designed to retain water in times of flooding, and to provide new areas of wildlife habitat and opportunities for public access in an area previously almost devoid of these.

Queen Elizabeth Olympic Park. © Natural England/S. Taylor

The north of the Park is shaped like a bowl, with natural flood management and drainage features such as swales and reed beds. It has been calculated that these features provide a flood risk management service for 5,000 homes (London Legacy Development Corporation 2014/15). A wide range of urban biodiversity has been recorded at the site including rare and notable species. This includes an increase in the number of breeding black redstarts; the park now provides a home for 6% of the country's population (London Legacy Development Corporation, 2014). This is achieved through a wide range of partner organisations working together to provide multiple benefits.

The importance of partnerships and funding (e.g. who is responsible for taking on assets)
Green infrastructure is most often and most successfully delivered and maintained through partnership. This allows the design to reflect the diverse needs of a location and can help to engage a wide audience, allowing representation of desires and input from many users and beneficiaries.

LOCATION
Where green infrastructure will provide the required adaptation function

PARTNERSHIPS
How we best provide the other elements

FEATURES
What green infrastructure will provide the required adaptation function, reinstating natural processes?

MULTI-FUNCTIONALITY
Ensure the best combination of functions are provided and maximised where possible and appropriate

Principles of good green infrastructure design

WWT London Wetland Centre. © Natural England/Sarah Taylor

References and further information

Further information

Useful websites and partnerships

- SuDS and green infrastructure guidance resources, Ciria
- Green Infrastructure Partnership website
- Urban Regeneration and Greenspace Partnership – including the 'benefits of green infrastructure knowledge portal' where you can search a publications database.
- European Conference on Biodiversity and Climate Change - Nature-Based Solutions to climate change in urban areas and their rural surroundings, Conference proceedings, BfN/ENCA
- Foresight, Cities Alive; rethinking green infrastructure, ARUP, 2014
- Natural England Access to Evidence Green Infrastructure Reports
- Natural England's Green Infrastructure Guidance
- Natural England report on Green Bridges: A literature review
- All London Green Grid
- Living Roofs

Trees and Woodlands

- Forest Research Benefits of Green Infrastructure summary & technical reports
- Realising the benefits of trees and woodland in the East of England

Ecosystem services and multifunctionality

- Defra, 2010. What nature can do for you? A practical introduction to making the most of natural services, assets and resources in policy and decision making
- The multifunctionality of Green Infrastructure, Science for Environment Policy, DG Environment, In Depth Report, March 2012.

Guidance and support

- Creating green roofs for invertebrates: A best practice guide, Buglife
- London Plan Policy Technical Report: Living Roofs and Walls, 2008

Case Studies

Natural England Case Study - Beam Parklands

Natural England Case Study - Mayesbrook Park

Natural England Case Study - Victoria Business Improvement District

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Case study - Exeter flood defence scheme case study

Case study - Howard Street - Experimental project looking at green infrastructure for surface water and urban diffuse pollution management.

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Part 5

Geology and geomorphology

Introduction

Compared to biodiversity and human infrastructure, the impacts of climate change on geological and geomorphological features and processes (sometimes referred to as 'geodiversity'[42]) are not as well considered. This is despite their critical role in providing the resources necessary to support human society and ecosystems.

The wide-ranging relevance of geological and geomorphological sites and processes include:

- the provision of resources (e.g. building materials, oil & gas, minerals and water);
- the parent-materials needed to form soil and cultivate food;
- scientific evidence that allows us to understand the processes that shaped and continue to shape our planet (e.g. recording evidence for past climate change and the consequences);
- cultural and aesthetic value (e.g. underpinning the landscape in which we live);
- providing the abiotic component of ecosystems.

Furthermore, a diversity of landscape features and natural geomorphological processes also provides resilience to climate change, for example, providing natural buffering to coastal and river flooding, and providing a range of microclimates and abiotic ecosystem services to support biodiversity and allow species to adapt to change.

The need to protect geological and geomorphological features and processes is widely recognised at spectacular or famous geosites (e.g. Jurassic Coast, Cheddar Gorge). However, other less prominent sites also require recognition and protection. In recent work by Scottish National Heritage, 8.8% of nationally and internationally important geosites in Scotland were found to be at high risk from climate change. The UK is a world leader in geo-conservation and has over 2000 geological Sites of Special Scientific Interest (SSSIs), seven geo-parks, two geological UNESCO World Heritage Sites, and an active and engaged community of professional and amateur geo-conservationists.

Often, it is the human response to climate change that poses the greatest risk to geodiversity, and particularly to active geomorphological features and processes. For example, hard coastal protection and river management schemes significantly disrupt natural processes and obscure geological exposures. Ironically, the resulting loss reduces our ability to model and predict future climate change as the geological record that gives us insights into these processes (e.g. peats, sediments, stalagmites, etc.) are destroyed.

This chapter examines the impacts of climate change on geological and geomorphological sites and considers appropriate approaches to managing sites in a changing climate. Where appropriate, links to case studies are given as examples. This chapter should be considered in conjunction with related biological habitats, which are intimately related to the underlying geology and to active geomorphology and soils.

In general, 'geodiversity' can be split into two broad categories, **static** and **active**:

42 Geodiversity: the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features. It includes their assemblages, structures, systems and contributions to landscapes.

Static sites - geological sites and caves

Static geological sites come in all shapes and sizes and we have split them into three sub-categories: **Extensive**, **Integrity** and **Finite**.

Extensive sites are those where the deposit is horizontally or laterally extensive behind or below the exposed site. These sites include quarries and pits, coastal cliffs and foreshores, river and stream sections, inland outcrops, exposures in underground mines and tunnels, extensive buried features, and road, rail, and canal cuttings. If damaged or destroyed, extensive features can (theoretically) be re-exposed or accessed at another location and/or destruction will simply expose a new, fresh face of the outcrop.

Integrity sites are more sensitive than extensive sites and are all geomorphological in nature. They include caves, karst and static (fossil) as well as active geomorphological sites (see section below). Here, activities in one part of the site, or indeed outside the site may adversely affect the whole site. Therefore, whole site or system management is essential to the successful conservation of integrity sites. In the case of static geomorphological sites, such as landforms created by past glaciations, the process that created the feature is no longer operating. Therefore these relict features are extremely sensitive and once destroyed are irreplaceable. Activities such as coastal protection, building and quarrying can be particularly damaging for integrity sites.

Finite sites are those with a limited lateral and horizontal extent, for example small scale features (e.g. particular mineral deposits or geological structures), fossils, some mines and tunnels, mine dumps, caves, karst (e.g. limestone pavement), static (or fossil) geomorphological features (e.g. drumlins, eskers, kettle holes), finite buried sites below ground, and sites of archaeological significance. If damaged or destroyed, finite deposits cannot be accessed or re-exposed elsewhere - they are permanently lost.

It is important to recognise that extensive, integrity and finite sites may be found together. For example, the main exposed rock beds in a quarry may be 'extensive', while other features (e.g. small scale features such as channel infills, tailings, or 'mineral dumps) can be finite. If the quarry is exploiting aggregates in a landform e.g. a glacial outwash fan, this is an integrity feature. Similarly, while coastal cliffs and foreshore may be extensive, sand dunes are integrity sites and dinosaur footprints and sea arches are considered finite. Furthermore, it is also important to recognise that the nature of a geological material will impact on how it behaves; for example, soft sediments (e.g. sand, gravel, and organic deposits such as peat) are usually more vulnerable to damage than hard rocks.

Active processes: geomorphology and soils

Geomorphology concerns physical, chemical, or biological processes that operate at or near the Earth's surface (e.g. aeolian, fluvial, glacial, periglacial, hillslope, mass movement, coastal/marine, and biological processes). Processes can be categorised as those that generate regolith by erosion and weathering, transport material, deposit material, and/or are strongly related to landforms (e.g. river meanders, kettle holes, eskers, sea arches) and sediment deposition. Their study by geomorphologists helps us to understand landscape history and dynamics.

Geomorphology is dynamic, with sites and processes evolving over a wide range of spatial and temporal scales. For example, the formation of glacial valleys occurs over millennia, while cliff retreat resulting from wave attack can sometimes be measured in metres per hour during storm events, and mass movement such as landslides and cliff collapse can occur in seconds. It is particularly important to recognise that geomorphology occurs on a landscape scale. For example, changes to the flow regime in the upper reaches of a river will impact on the river flow rate downstream, which in turn will impact on the evolution of the water course through sediment erosion, transport, and deposition, and flood plain processes. In the context of this manual, active geomorphology is considered to include the formation and evolution of soils. Active process sites are considered to be integrity sites, where a whole system approach to management is needed for effective conservation.

Potential climate change impacts

Geological sites are often perceived to be 'permanent' features, while active geomorphological processes are either seen as something to be maintained in their current form, or something that requires engineering to reduce impact on people and infrastructure. However, both environmental change and human modification pose a significant threat to our geological and geomorphological heritage and assets. In particular, the impacts of global climate change risks damaging these features irreparably, with wide ranging implications for landscape resilience, natural resource availability, and biodiversity. The table below outlines the main consequences and potential impacts of climate related change on both static and active geological and geomorphological sites, processes, features, and soils.

Cause	Consequence	Potential Impacts	
		Geological Sites and Caves	Geomorphology and Soil
Hotter summers and milder winters	■ Increased vegetation growth. ■ Decrease in freeze/thaw processes	■ Increased vegetation may damage or obscure exposures and/or limit access. ■ Reduction in damage to geological features.	■ Increased vegetation may affect natural processes. ■ Disruption to geomorphological processes (e.g. reduced sediment transport and deposition). ■ Changes to the formation and evolution of soils. ■ Loss of patterned ground development.

Cause	Consequence	Potential Impacts	
		Geological Sites and Caves	Geomorphology and Soil
Drier summers	■ More frequent droughts. ■ Increased risk of wild fire. ■ Reduced water levels in rivers, streams, lakes, and reservoirs ■ Vegetation loss. ■ Drying out of peat deposits.	■ Drying out of sediments (particularly 'soft' sediments) may increase vulnerability to erosion. ■ Exposure of previously obscured geological sites. ■ Possible collapse of poorly consolidated sedimentary exposures (e.g. sand.) ■ Erosion may expose new geological sites for extensive deposits. Finite sites may be damaged. ■ Fires may damage or re-expose geological sites. ■ Vegetation loss may increase the vulnerability of geological sites to erosion and/or re-expose new sites. ■ Drying out of peat sites may destroy fossils through oxidation and therefore damage these archives of palaeo-environmental change.	■ Sediments and soils become more vulnerable to erosion, particularly during flooding events. ■ Fires may result in vegetation loss and a subsequent increase in vulnerability to soil erosion. ■ Vegetation loss may increase vulnerability to soil erosion, in turn leading to greater sediment transport and deposition. ■ Drying out of peat sites may destroy fossils through oxidation and therefore damage these archives of palaeo-environmental change.
Wetter winters	■ Increased water levels in rivers, streams, lakes, reservoirs, caves, and ground water. ■ Waterlogging of soils and sediments.	■ Flooding may damage or obscure exposures and/or limit access. ■ Increased flow in streams and rivers may increase erosion and remove material or re-expose geological sites. Finite sites could be damaged. ■ Increase in slope instability and possible collapse of poorly consolidated sediments. Increased mass movement on coastal cliffs may remove material or re-expose geological sites. Finite sites could be damaged. ■ More frequent occurrence of sink holes. ■ Re-deposition of sediments may obscure geological sites. ■ Increased rainfall may support and protect peat deposits. ■ An increase in landslides and slope failures may re-expose and/or obscure geological sites. Finite sites could be damaged. ■ Altered hydrology in cave sites may affect the extent and distribution of flooded passages, and expose or remove cave sediments.	■ Flooding may alter the landscape by washing away soils, changing the position of river channels, and initiating the formation of new geomorphological features. ■ Increase in sediment transport and deposition. ■ Groundwater flooding may become more frequent. ■ An increase in landslides and slope failures may alter the landscape and alter natural processes. New geomorphological features such as sink holes may be created. ■ Increased rainfall may support and protect peat deposits.

Cause	Consequence	Potential Impacts	
		Geological Sites and Caves	Geomorphology and Soil
Increased frequency of extreme events	■ High winds. ■ Highly concentrated rainfall episodes. ■ Rapid freeze/thaw and/or wetting/ drying. ■ Water-logging of soils and sediments ■ Reduced landscape recovery times between events	■ Overturned tree roots may damage underlying geology. At soft sediment sites, sediments exposed beneath overturned trees may be vulnerable to increased erosion. ■ Flooding may damage finite sites or obscure exposures and/or limit access. ■ Increased flow in streams and rivers may increase erosion at geological sites leading to damage to finite sites or improvement of the exposure in extensive sites. ■ Re-deposition of sediments may reveal or obscure geological sites. ■ Erosion may expose new geological sites. ■ Impacts to outcrops may destroy or expose geological features and/or increase vulnerability to erosion. ■ An increase in landslides and slope failures may re-expose and/ or obscure geological sites or reveal new sites. Finite sites may be damaged.	■ Erosion of exposed soils. ■ Flooding may wash away soils and alter the landscape (e.g. change the position of river channels). ■ Increase in sediment transport and deposition. ■ Increased generation of new soils. ■ Increase in landslides and slope failures may alter the landscape and alter natural processes. ■ Amplification of the above consequences.
Increased atmospheric CO_2 concentration	■ Increased vegetation growth. ■ Changes in the acidity of meteoric water.	■ Increased vegetation may damage or obscure exposures and/or limit access. ■ Dissolution of karst features and caves.	■ Increased vegetation may affect natural processes. ■ Change in soil chemistry and other properties may increase vulnerability to erosion.
Global increase in temperature	■ Rising sea level. ■ Changes in wave action.	■ Foreshore lowering (where the low water mark moves inland faster than the high water mark, so that the foreshore becomes steeper and narrower) may reduce the area of exposed coastal geology. ■ Geological sites may become damaged and/or obscured. New geological sites may become exposed. ■ Reduced duration of access to geological sites at low tide. ■ Erosion and foreshore lowering may expose new geological sites. ■ Increase hazards associated with accessing coastal geological sites. ■ Erosion may expose new geological sites.	■ Geomorphological features such as spits may be damaged and/or obscured. ■ New geomorphological features such as beaches and spits may form. ■ Alteration to natural processes may change estuary processes and features and alter the landscape. ■ Increase in hazards associated with accessing coastal geomorphological sites. ■ Increased erosion may result in more landslide activity. ■ Changes in coastal processes such as sediment movement will lead to the creation and destruction of coastal landforms.

Cause	Consequence	Potential Impacts	
		Geological Sites and Caves	Geomorphology and Soil
Human responses to climate change	■ Hard engineering schemes, such as sea walls, river bank defences, flood barriers, and drainage schemes.	■ Netting and/or concrete walls used to support cliff faces may damage, obscure or reduce access to geological sites, and may also prevent erosion. ■ Altering the position of sediment deposition may obscure geological sites or reveal new sites. ■ Increased flow in engineered streams and rivers may increase erosion and damage or re-expose geological sites. ■ Flooding of alternative locations may damage or obscure exposures and/or limit access.	■ Alteration to natural processes (e.g. disruption of sediment transport along coastline, preventing flooding of rivers onto natural flood plains) may increase the severity of climate related problems in the future (e.g. more intensive flooding) and/or impact on adjacent areas (e.g. loss of neighbouring beaches).

Adaptation responses

Natural systems are dynamic and the most sustainable management approach requires an acceptance of the inevitability of change by, for example, allowing rivers to shift their course or the renewal of cliff exposures through erosion and collapse. Providing a space for natural processes to proceed (e.g. the re-creation of flood meadows in river basins) is not only practical, but has broader benefits for society (e.g. avoiding the unintended consequences of hard engineering schemes such as the redistribution of sand resulting from groyne installation). Sustainable management requires an adaptive long-term view that works with the changing landscape, focusing on conserving and ensuring a diversity of geological sites and geomorphological features and processes.

Given the global driving forces behind climate change and the scale of the impacts, preventing or completely mitigating against damage to geosites is unrealistic, and practically, socially and financially unsustainable. In particular, the engineering requirements for such an approach would be likely to inflict greater damage on the diversity of geological and geomorphological features, not only at the site in question but also within the wider landscape (e.g. further downstream of a river defence project) and should be avoided. In addition, attempting to preserve geosites in their current state is not only impractical but also counter-intuitive, as change is often the norm for geodiversity sites, which by their very nature are the products of an ever-evolving climate and environment. In fact, the impacts of climate change on geosites can often be positive and provide new opportunities, for example by exposing new features. Therefore, active conservation efforts are only encouraged for finite sites where loss or damage is inevitable, in which case a policy of rescue and/or record should be encouraged (i.e. remove key specimens, analyse, write up, and archive material and documents).

The following strategies should be considered when addressing the issue of climate change adaptation at geosites (see also Wignall *et al* (2018 a,b):

1. Identify the climate projections for the local area, specifically those variables that are likely to affect geosites, such as projected changes in rainfall, temperature and water levels.
2. Undertake an audit of geological and geomorphological features of interest. Many stakeholders are unaware of the breadth of geomorphological processes and features, soil

types and geological outcrops within an area of interest. Before conservation efforts can be considered, these should be identified and if possible mapped. Audits should be as detailed as possible, and include an assessment of relevant site characteristics, for example:

- The location and nature of geosites and features of interest on a particular site.

  Case studies:

  Geological Conservation Review (audit of nationally and internationally important geosites in Great Britain which is the evidence base for geological SSSIs);

  North Pennines Area of Outstanding Natural beauty (AONB) Geodiversity audit and action plan.

- The magnitude and frequency of past events (e.g. landslides, floods, changes in the position of river channels) using all available data (e.g. Ordnance Survey and other historical maps, local archives, local knowledge, comparison of Google Earth images).

  Case studies:

  Palaeo-flooding recorded in Brotherswater sediments,

  Flooding of the Feshie and Spey alluvial fan (Werritty, Hoey & Black, 2005);
  Slope instability at Giant's Causeway.

- Analysis of soil characteristics such as chemistry and structure to assess vulnerability to erosion and remobilisation, and/or the analysis of sediment/outcrop characteristics to assess vulnerability to erosion or collapse (e.g. level of water saturation, cohesion between sediment grains).

  Case study:

  Derwent Valley Mill World Heritage Site (Howard *et al* 2016).

- Record of geosites in their current state (e.g. photographs, maps, diagrams, measurement of key features, stratigraphic logs of geological exposures, sample collection from different geological units).

3. Using site categories, identify those sites, or features and areas within sites, most vulnerable to the impacts of climate change. Use a risk assessment approach to evaluate the likelihood and severity of impacts.

4. Consider mitigation and management options. For many sites there may be no practicable options to prevent and reduce the impact of climate change. At such sites, management options should focus on creating the space to allow natural features to evolve unimpeded. Where possible for extensive sites, identify new geological exposures or areas to access the geological interest in buried sites that may replace those damaged or obscured, for example, a new river-bank section formed by the change in a river's course or an outcrop obscured by vegetation that can be re-exposed. If necessary, intervene by, for example, clearing vegetation where roots are damaging geological material or where plants obscure a site, artificially protecting small-scale features (e.g. using wind breaks or drainage ditches), and, where loss is inevitable, rescue and/or record small-scale features such as fossils and archaeological remains.

   Case studies:

   Rescuing fossils on the Jurassic Coast - The West Runton Elephant;

   Preservation of rock-art in Northumberland (Giesen *et al* 2014)

A heavily vegetated section at Barnfield Pit (Swanscombe Skull Site SSSI and National Nature Reserve in Kent) which was re-exposed using a mechanical excavator for the European Society of Human Evolution (ESHE) visit in September 2015. The section exposes the Boyn Hill Terrace (Boyn Hill Gravel Member) deposits of the Lower Thames which were deposited during the Hoxnian Interglacial (MIS 11) approximately 400,000 years ago. (Simon Lewis/Queen Mary University of London).

5. Draw up climate change adaptation plans. Wherever possible, climate change adaptation plans for geodiversity should aim to:

- Work with natural processes and avoid 'hard' engineering solutions such as concrete cladding or thick wire netting that can damage or obscure cliffs, or beach groynes that interrupt the natural movement of sediment along the coast. Where engineering solutions are considered necessary, priority should be given to 'soft' approaches that use natural materials, and as far as possible mimic the natural environment. Examples include planting natural hedgerows as windbreaks, creating flood meadows to alleviate pressure during periods of high river flow, and restoring coastal wetlands to buffer the impacts of sea level rise.

- Be integrated with biodiversity management. Examples include keeping records that link particular species to specific geological or geomorphological environments; integrating geological and biological monitoring programmes; and promoting landscape heterogeneity.

- Engage with local stakeholders to foster a landscape-scale approach to adaptation. This is particularly important for geomorphological processes that cross boundaries and are impacted by actions carried out at distant locations, such as river flow regimes and sediment transportation at the coast.

6. Site monitoring. Where possible, implement a monitoring system to detect change, such as periodic fixed-point images. Monitoring data should be stored in an easily accessible location and format, and should be regularly analysed to identify rates and processes of change. In general, finite sites should be prioritised.

   Case studies:

   Windbreaks at North Doddington Farm,

   Preservation of rock-art in Northumberland.

Relevant Countryside Stewardship Options

Funding to support adaptation for geodiversity is available through the **Countryside Stewardship scheme**. The following options are relevant for protecting geological and geomorphological features and processes:

FM1 Management of geodiversity features

This supports positive land management schemes that aim to protect sensitive geological features from damage. This programme is only available for Sites of Special Scientific Interest (SSSIs).

HE1 Historic and archaeological features protection

Many geological features also have a historic and/or archaeological significance (e.g. mine-related features, Quaternary deposits containing archaeological artefacts). This option supports physical works that aim to conserve or protect individual historic features in the landscape.

SB3 Tree removal

One of the most common issues at geological sites is overgrowth from trees and other vegetation. This option supports the removal of trees to restore environmental features. A related option, SB6 (rhododendron control), can be used for rhododendron removal from environmental sites.

BN11 Planting new hedge

The planting of a new hedgerow can reduce soil erosion and runoff.

TE10 Coppicing bankside trees

The coppicing of trees can be used to stabilize the banks along streams and rivers, which may be de-stabilised by increased water flow from high rainfall.

RP9 Earth banks and soil bunds

Support for the construction of earth banks and soil bunds is available in areas targeted for a reduction in water pollution from agriculture or in areas targeted for flood risk reduction. These structures slow the movement of water, slow flows during high rainfall, reducing the risk of soil erosion and downstream flooding and control water levels. Related options include BN3 (earth bank creation) and BN4 (earth bank restoration).

RP10 Silt filtration dams or seepage barriers

Support for the construction of silt filtration dams or seepage barriers is available in areas targeted for a reduction in water pollution from agriculture or in areas targeted for flood risk reduction. These features slow the movement of water, thereby protecting against soil erosion and downstream flooding.

RP11 Swales

Support for swale construction is available in areas targeted for a reduction in water pollution from agriculture. However, they also help to reduce the risk of soil erosion and runoff.

Further information and advice

Advice on geological features and their conservation is available from a number of sources.

National

At the UK level, support for geodiversity action is coordinated through the **UK Geodiversity Action Plan**, the **English Geodiversity Forum**, the **Scottish Geodiversity Forum** and Geodiversity Charters in **England** and **Scotland**. Various national bodies can provide information on the extent and significance of geological and geomorphological features and can often provide advice on conservation measures. These bodies include the **British Geological Survey** (BGS) and Natural England (and its equivalent agencies in Scotland and Wales, Scottish Natural Heritage and Natural Resources Wales). Relevant resources include Natural England's **Geological conservation guide to good practice** and various freely available geological tools published by the BGS, including the **Geology of Britain viewer**; the **iGeology and mySoil** apps, **borehole records**, the archive of **geological photographs**, and the BGS **maps portal**.

Geology groups and associations

There are many geological societies, local geology groups and university departments that hold information about local geological and geomorphological features, and which may be able to offer advice on conservation measures. Examples include **Geoconservation UK**, the association of local geoconservation groups; the **Geological Society of London**: the **Geologists' Association**; the **Quaternary Research Association**; and the **Geology Trusts**, representing county-based geoconservation groups.

The River Restoration Centre

The **River Restoration Centre** provides information and advice on best practice for river restoration and catchment management. Its website includes numerous case studies covering different river processes and restoration techniques.

Relevant case studies

Cheviots flood impacts study

Commissioned by the Cheviot Futures project, a detailed study was conducted into the impacts of severe and rapid flooding within the Breamish and Till river catchments, Northumberland (Oughton, Passmore & Dilley 2009). These are geomorphologically active lowland rivers draining the impermeable bedrock of the Cheviot Hills. They are in formerly glaciated landscapes with high bed load and high channel mobility. The nationally important river and floodplain habitats are closely related to the active geomorphological processes operating. Here there has been a notable shift in approach from active management/engineering during the 1980s and 1990s, to working with the river during the 2000s and 2010s. This has been exemplified by the response to extreme rainfall events in 2008, December 2015 and January 2016, which led to flooding and channel avulsion (rapid channel shift) (see photograph below). This damaged infrastructure including powerlines and roads. The new approaches adopted include whole catchment/floodplain approaches, soft engineering and positive partnership working between landowners, government agencies, utility companies and others through the Tweed Forum and River Till restoration project. Through this, trials of innovative flood management techniques are taking place and work is being carried out to identify and adapt infrastructure at risk. To date, benefits have included improvements to habitats and improvement in the mobility of the rivers and connections with their floodplains.

Double channel avulsion on the River Coquet (River Coquet and Coquet Valley Woodlands SSSI) in Northumberland, which occurred in January 2016 as a result of extreme rainfall. © Natural England /Robert Cusson

Palaeo-flood records from Brotherswater, Cumbria

Organic sediments in Brotherswater, a temperate lake in Cumbria's Lake District, were used to investigate the frequency and magnitude of past flooding events. In particular, changes in sediment chemistry and particle size allowed for the identification of flood deposits. These palaeo-flood data were compared to local river discharges to identify detection thresholds for flood events in lake sediments.

Preservation of open-air rock art in Northumberland

This case study (Giesen *et al* 2014) is explicitly focused on rock-related archaeological sites. However, the approach could be adapted for finite geological sites at threat from environmental change (e.g. small scale fossils or structural features in a geological exposure, and karst sites).

Rock art includes the use of pictographs (paintings) or petroglyphs (engravings and carvings) on natural rock surfaces. In Northumberland, over 1200 rock-carving sites have been identified, usually on open-air isolated geological outcrops. These outcrops are threatened by environmental factors, including wind exposure, freeze/thaw cycles, air pollution, changes in vegetation cover, and changes in local soil chemistry. A study was conducted to assess a range of ambient geochemical and physical descriptors at rock panels with different levels of deterioration. Data were then used in conjunction with present and past environmental conditions to assess how rock art sites are affected by environmental change. Finally, a four-step approach to managing rock-art sites was developed: 1) collection of data on ambient conditions at a site; 2) identification of specific weathering mechanisms at work; 3) prioritisation of sites based on relative importance and state of preservation; 4) development of management strategies (e.g. reduction in wind exposure, improved site drainage, immobilization of soil salts).

Derwent Valley Mill World Heritage Site, Derbyshire

In the Derwent Valley, the changes in geomorphological processes that accompany climate change, such as changes in the flow and position of rivers and flood plains, pose a management challenge. In particular, there is a need to predict and monitor the continued release of heavy metals, originally released during historic mining activity and now trapped within soils and sediments. Increased flooding from higher rainfall and more frequent extreme weather events can remobilise these heavy metal deposits. To improve the management of this issue, an integrated approach was used to assess the spatial distribution of areas of concern. This study (Howard *et al* 2016) utilised multiple data sources (e.g. Environmental Agency, British Geological Survey, Ordnance Survey, local council archives, and the National Archives) to recreate river flood records in order to predict future events.

River Dulais bank protection

To combat bankside erosion, a soft engineering approach was utilised to stabilise a highly mobile reach of the Dulais river, Wales. Tree trunks were laid sideways and sunk into the riverbank, with the tree roots projecting out from the bank into the river flow. Tree roots deflected the flow of water, reducing erosion along the banks.

Erosion of a mine dump at Tynebottom mine
Erosion of mine spoil at Tynebottom mine by the River South Tyne (River South Tyne and Tynebottom Mine SSSI) was a cause for concern because of the loss of scientifically important mineral samples, loss of land and the potential for pollution to the river system. An engineered 'logjam' was proposed as a created 'natural' solution. Tree stumps were driven into the bank, with their roots pointing back into the river. The area behind the stumps was back-filled with large gravel and river sediments and vegetation started to accumulate in the roots (see photograph below). This approach was quite innovative and initially worked very well. Unfortunately in December 2015 the extraordinary weather conditions produced by Storm Desmond partially destroyed the 'log jam' leaving the site vulnerable again. However, the weight of water travelling down river caused the river channel to switch and erosion has now naturally lessened in the area of the mine spoil.

Engineered 'log jam' - soft engineering solution preventing erosion of the nationally important Tynebottom Mine spoil (River Tyne and Tynebottom Mine SSSI). © Natural England /Simon Stainer

Geomorphological Sensitivity Zoning at the Feshie and Spey Alluvial Fan, Scotland
To balance the needs of conservation and flood management within an alluvial fan at the confluence of the Feshie and Spey rivers, geomorphological sensitivity zoning was carried out. Assessment focused on the probability of an area becoming destabilized by floods within a given timeframe (Werritty, Hoey & Black 2005). Each area of the fan was classified as one of the following: 1) highly sensitive and dynamic where no engineering works should be attempted; 2) medium sensitivity where permitted engineering works require careful management and monitoring; or 3) low sensitivity where appropriate river engineering is permitted.

Scottish Geosites and the management of climate change impacts

Work recently undertaken by Scottish Natural Heritage has provided numerous examples of geological and geomorphological sites at risk from climate change and for each considered possible management actions. Examples include: managed re-alignment of a flood embankment at Gruinart Flats SSSI to reduce the impacts of coastal squeeze on saltmarsh; shoreline woodland conservation and/or tree planting at Endrick Mouth and Islands SSSI to protect against erosion caused by water level rise in the loch; promotion of 'natural space' and resisting of plans for river engineering along the River Clyde in order to protect natural meandering processes, and the establishment of monitoring programmes at Abernethy Forest and Tynaspirit to check for signs of drying out of bog pollen features.

Slope instability and site management implications at Giant's Causeway, Northern Ireland

The nature and rate of change associated with dynamic coastal processes at the Giant's Causeway has evolved and intensified as a result of climate change. These processes threaten to damage or destroy the unique geological outcrops at the site, and to impede access to the site along coastal paths. To ensure the continued effective management of this World Heritage Site, a mapping study was conducted to provide base-line information and establish protocols for assessing future environmental change. In particular, interactive site maps were produced using GPS and GIS. These maps are updatable, allowing site managers to conduct continuous monitoring of change.

Rescuing Fossils on the Jurassic Coast

Part of the Jurassic Coast World Heritage Site, the Undercliffs National Nature Reserve (NNR) near Lyme Regis in Dorset is well known for its foreshore 'Ammonite Pavement'. In early 2017 winter storms broke up part of the pavement, and the Natural History Museum, in collaboration with Natural England, rescued a number of the larger loosened ammonite blocks. Some are now on display locally and the remainder are at the Natural History Museum. This is part of an on-going research project looking at late Triassic - early Jurassic faunal and environmental changes. Rescuing the storm damaged blocks has provided an opportunity to examine the fossil fauna and palaeoecology at a level of detail that previously was not possible.

Rescuing the ichthyosaur in the Undercliffs NNR on the Jurassic Coast World Heritage Site in Dorset. © Richard Edmonds

Also in the Undercliffs NNR, the recent discovery of an ichthyosaur led to a spectacular rescue of the specimen. The cliff location of the ichthyosaur presented the risk of loss due to erosion and cliff fall. Given the potential importance and rarity of the fossil, Natural England gave permission for its rescue. Once removed, it was carefully conserved and then analysed at Bristol University. The specimen, which is currently on display at the Charmouth Heritage Coast Centre, was particularly well preserved (including skin preservation) and is potentially a new species.

The West Runton mammoth

Following a storm in December 1990, local residents in West Runton, on the North Norfolk coast, discovered a large bone sticking out of the cliff. They contacted Norfolk Museums Service who confirmed it was the pelvic bone of a steppe mammoth *Mammuthus trogontherii*. In January 1992 an exploratory dig was carried out, followed by a major rescue excavation in 1995. This excavation not only removed the mammoth's skeleton, but also sampled the sediments surrounding it, which contained fossils of snakes, frogs, small mammals and birds. The entire excavation took 3 months and if it had not taken place, the mammoth would have been lost to the sea in less than a decade.

The soft sediment Ice Age cliffs at West Runton SSSI, North Norfolk, where an almost complete mammoth skeleton was discovered in 1990, and rescued during a major excavation in 1995. © Natural England /Naomi Stevenson

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Part 6
Access and recreation

Introduction

This chapter describes the potential direct and indirect impacts of climate change on a range of public access resources, and outlines possible adaptation responses available to those involved in their management.

Recreation in the natural environment, whether through organised sports and events or more informal activities, is important for our health and quality of life, and in sustaining local and national economies. *The Monitor of Engagement with the Natural Environment Headline report from the 2015-16 Survey* (Natural England 2017a) estimated that there were 3.1 billion visits to the natural environment in the recording year March 2015 to February 2016, including 1.35 billion to the countryside, 0.32 billion to the coast and coastal resorts, and 1.45 billion to urban greenspace. These visits included 519 million visits that took place using access networks, i.e. paths, cycleways and bridleways. *The 2019 Monitor of Engagement with the Natural Environment (MENE) Headline Report* (Natural England 2019) indicates that more people are visiting the natural environment than ever before, with numbers having increased since 2015/16.

Access to the environment is very dependent on physical infrastructure like footpaths and cycle paths, parks, and accessible areas such as greenspace and open access land. These resources are likely to be affected significantly by the effects of climate change, for example by more frequent incidences of high rainfall and flooding, erosion inevitably creating issues for future maintenance and visitor management. Patterns of recreational use are also likely to change in response to changing climatic conditions, which could create pressures on other resources such as protected wildlife sites and species.

Climate change will impact on access resources in all parts of the country, but is likely to be more of a concern in areas that experience extreme weather events and/or where change is more rapid, such as on eroding coastlines and in the uplands, and in areas with high visitor pressure. However, McEvoy *et al* (2008) note that the relationship between climate and wider visitor demand is complicated and that 'climate influence on visitor behaviour is more likely to be overshadowed by socio-economic trends.' MENE data too indicates that while weather is significant in determining people's recreation decisions, other factors such as available time and income are just as, if not more, significant.

Access and recreation resources

Public access and recreation resources on land and water can be broadly divided into **linear routes** and **areas**. These are described briefly below:

Linear routes

Public Rights of Way (PROW)

PROW are routes upon over which the public has the legal right, depending on the type of route, to walk, ride a horse or bicycle, or drive a motor vehicle. There are about 186,000 km of rights of way in England, which represents about a third of the total highways network. This network provides the crucial linear infrastructure for accessing much of the natural environment.

Paths can have firm sealed surfaces, unsealed surfaces (such as an aggregate material) or, as is the case with most rural paths, will be unsurfaced. Public rights of way are generally managed by local highway authorities, who have a duty to maintain and keep them open for the public to use. Landowners also have legal duties associated with PROW, including ensuring that they are not obstructed or overgrown.

National Trails and other promoted routes
There are several types of promoted route in England, including the statutory National Trail network and England Coast Path (which will also correspond in many places with existing PROW), longer promoted routes such as the Coast to Coast path and many shorter local and regional trails. The National Trail network alone is 4000 km long, and the England Coast Path, when completed, will cover 4500 km and have associated accessible areas by virtue of its coastal margin. Both are managed largely by partnerships led by local authorities.

Cycle routes
Many cycle routes have been established along the routes of disused railway lines or on forest tracks, and will generally have some sort of improved surface, though this could be sealed or unsealed. The National Cycle Network, co-ordinated by Sustainable Transport (British Cycling Organization) (SUSTRANS) provides over 22,000 km of on and off-road routes. Many cycle routes have shared use with walkers, wheelchair users, and sometimes horse riders.

Permissive routes
In addition to statutory rights of way, walking and riding routes can be provided voluntarily by individuals or organisations. Provision can be small- scale, involving individual land-owners and often as part of an agri-environment scheme agreement; or larger and more formalised, as is the case with most of the 3200 km canal towpath network managed by the Canals and Rivers Trust.

Rivers and canals
Rivers and canals are important for various water-borne activities such as fishing, swimming and boating, and river banks and towpaths provide valuable open space and access routes. However, there is no right of navigation or public access to banks on most rivers.

Areas

Areas for public access and recreation range from small scale urban and country parks and more informal green spaces, to large tracts of statutory open access land covering many square kms.

Open Access land and other open access rights
The Countryside and Rights of Way Act 2000 (CROW) created a general right of access on foot to almost 12,000 km^2 of land mapped as: mountain, moorland, heath and down. (**Rights of Way and Accessing Land**) Access rights also exist on the various types of common land and on land dedicated under CROW by private land owners and public bodies, including the Forestry Commission, which has dedicated its freehold woodland estate, and Natural England, which has dedicated suitable National Nature Reserves. Access rights under CROW also apply to the margin of the England Coast Path. Whilst the majority of rights are on foot, access rights can include higher rights, particularly for horse riders.

Nature Reserves
Nature reserves, including statutory **National Nature Reserves** (NNRs), Local Nature Reserves (LNRs) created by local authorities, and sites managed by conservations bodies such as the RSPB, National Trust and Wildlife Trusts, are generally managed for public access as well as conservation. Nature reserves cover a significant area of England, with NNRs accounting for over 94,000 ha and LNRs nearly 40,000 ha. Much of the public access to nature reserves is via the linear routes mentioned above, but some are open access.

Urban and country parks
There are various types of park, ranging from more formal, urban parks to less formal 'managed' countryside found in country parks. Parks are important, both for providing accessible greenspace in urban areas close to where people live, and for providing popular destinations further afield, often at the interface of town and countryside. England also has extensive areas of private parkland, often as part of landed estates, with varying degrees of public access.

Greenspace
Greenspace Scotland defines urban greenspace as, 'any vegetated area of land or water within or adjoining an urban area'. It forms an important part of the green infrastructure of towns and cities and can include parks and gardens, informal recreation spaces, domestic gardens, village greens, urban commons, and areas of natural and semi-natural open space. It also includes green corridors, e.g. rivers and canals (including their banks), road and rail corridors, cycle routes and pedestrian paths. Natural England, in **Nature Nearby** (2010), adopts a broad definition and identifies *natural greenspace* as 'places where human control and activities are not intensive so that a feeling of naturalness is allowed to predominate' and *accessible greenspace* as, 'places that are available for the general public to use free of charge and without time restrictions'.

Greenspace is managed by a range of bodies, including local authorities, community groups, charities, and wildlife trusts. Some greenspace may not be managed at all, but can still provide informal access and recreation opportunities for urban populations.

Coasts and inland water bodies
Coastal areas are a focus for recreational activities based on and along the shoreline, including visiting beaches, coastal resorts and beauty spots, walking on coast paths, the use of sea-cliffs for climbing, and coasteering. Offshore and near shore activities will include sailing, angling, surfing/sail-boarding, jet-skiing and scuba-diving. Lakes and reservoirs are also often focal points for recreational visits and activities.

Potential climate change impacts

This section outlines the potential impacts of climate change on recreational sites and routes and considers the critical factors that are likely to exacerbate or mitigate these impacts.

Scottish Natural Heritage (2011) identified two main types of pressure on access resources: *chronic pressure* from ongoing climate trends and *acute pressure* from extreme weather events. These in turn will translate to widespread and more predicable *chronic impacts* and less predictable, more localised a*cute impacts*.

Impacts on access resources can also be *direct* or *indirect*. Direct impacts will commonly include the immediate effects of physical conditions and process, i.e. the effects of weather, weathering and subsequent erosion. Indirect impacts include behavioural responses to climate change, such as changes in recreation patterns or changes in land use, and their impacts on access resources. The following table summarises the likely impacts of projected climate change on recreation areas and routes. These are discussed in more detail in the subsequent paragraphs.

Cause	Consequences	Potential Impacts	
		Linear routes	Areas
Longer, warmer and drier summers	■ More frequent periods of drought ■ Drier vegetation, leading to increased risk and severity of wild fires. ■ Longer growing seasons, leading to increased vegetation growth. (Potentially more flammable vegetative material for wildfires.) ■ Changes in visitor behaviour in response to milder winters, hotter summers, and an extended warm season, potentially leading to more outdoor visits and an increased use of some recreation routes and areas. ■ Reduced water levels in rivers, streams, lakes, and reservoirs. ■ Increased risk of blue-green algae.	■ Path surfaces are more likely to break up and erode, due to desiccation. ■ Paths are more likely to become overgrown, and will become less attractive to users if they are blocked or difficult to use. ■ More frequent maintenance may be needed by Highway Authorities, National/ Coastal Trail partnerships and landowners to keep routes open and comply with legal obligations. ■ Visitor pressures on sensitive wildlife sites may increase at peak times and over an extended warmer 'visiting' season, increasing the risk of physical damage or disturbance ■ Access to some rivers, streams and lakes for some forms of water-based recreation may be restricted, potentially placing more pressure on available sites.	■ More frequent closures/restriction on Open Access land due to fire risk. ■ Parks and other more formal areas of open space may need to be mown more frequently (although not during droughts). ■ Visitor pressures on sensitive wildlife sites may increase at peak times and over an extended warmer 'visiting' season, increasing the risk of physical damage or disturbance, especially coastal sites (Simpson 2013).
Milder winters and higher winter rainfall	■ Increased rainfall and run-off could lead to soils becoming saturated. ■ Saturated soils more prone to surface damage ■ The frequency and magnitude of flood events is likely to increase. ■ Water levels in some water bodies may increase. ■ Less erosion in winter months due to reduced frost heave.	■ Higher rainfall and more intensive rainfall events are likely to cause more frequent and extensive erosion of routes, making them more difficult to use particularly for less physically able users and for longer periods ■ More erosion material could be deposited on routes, causing obstructions and requiring more work from highways authorities and landowners to keep surfaces clear. ■ If paths become more difficult to use, users may divert around muddy or waterlogged areas, which could affect surrounding land and have negative impacts on user enjoyment, farmland and biodiversity. ■ Paths would be more prone to damage from farm traffic, recreational motor vehicles, horse riders and other users. ■ Greater need for path surfacing to allow for the passage of the ordinary traffic of the neighbourhood ■ Flooding and erosion could damage or destroy waterside paths and restrict their use, and could lead to permanent loss of public rights of way. ■ Higher water levels could lead to increased risks to public safety, particularly on riverside paths. ■ In some upland and exposed areas, less management and repair of path surfaces may be required.	■ Flooding could cause a reduction in the area of accessible land within open access land and parks. ■ Wetter areas such as bogs and marshes may become unusable.

Cause	Consequences	Potential Impacts	
		Linear routes	Areas
More frequent extreme weather events,	■ More frequent and more severe periods of high winds and intense rainfall, leading to storm damage, flooding and rapid water-logging of soils ■ More frequent droughts and extreme heatwaves: ■ Increased health risks from extreme heat and associated higher pollution levels	■ More frequent flash floods, caused by overland flow exceeding the infiltration capacity of the soil, will result in more acute erosion/deposition events. ■ Obstruction and acute physical damage to paths, caused by falling trees in woodland areas and debris transported by flooding/ overland flow, will have an impact on maintenance regimes and costs. These impacts will be difficult to predict, and managers will have to be prepared to respond urgently to unforeseen events. ■ Low water levels in navigable rivers/ waterways may entail low flow restrictions for craft ■ Rapid desiccation of soils could result in damage to path surfaces. ■ Participation in more physical outdoor activities may put participants at risk of heat and pollution related health issues (heatstroke, sunburn, breathing issues, exposure to toxic algal blooms in lakes etc.)	■ Water-logged areas could become less attractive and unusable for visitors ■ Damaged infrastructure could lead to a long-term reduction in tourist revenue to local communities and business. ■ Remedial flood defence work at coasts and along watercourses may affect the quality and extent of public access, but may also provide opportunities for new access, e.g. on flood banks and at managed retreat sites. ■ An increased fire risk could lead to access restrictions ■ Prolonged hot weather could lead to greater use of inland waters and coastal areas water resources.
Rising sea levels and more frequent storm surges	■ Rising sea levels and more powerful waves will lead to increased rates of coastal erosion, particularly on unprotected soft coasts, resulting in more severe cliff retreat and a loss of beaches and dune systems. ■ More frequent storm surges and subsequent flooding will affect low-lying coastal areas and associated access resources.	■ Coastal paths will be at greater risk of erosion and are likely to require more frequent maintenance. Where the coastline is unprotected they could be lost altogether as the coastline retreats landwards. Paths without the capacity to be re-located further inland could be lost permanently. ■ The **England Coast Path** is being established with the facility for 'roll back' as the coast changes, but accelerated erosion rates due to climate change could necessitate ongoing higher repair and general maintenance costs. ■ Increased erosion could increase the risk of accident for coast path/margin and beach users.	■ Effects on beach areas and profiles can alter access to beaches and the available space for visitors. ■ A higher risk of subsidence and rock-fall at coastal cliffs can increase risks to beach users, coastal walkers and climbers. ■ Any reduction in the area of coastal habitats and sites of high biodiversity value could result in higher visitor pressures at remaining sites. ■ Chronic, long-term changes may affect the overall character of destination areas with possible changes in visitor numbers and behaviours.

Longer, warmer and drier summers

Warmer and more 'reliably warm' summers may lead to more people holidaying at home than abroad (Giles & Perry 1998). Coombes and Jones (2010) note that climate change is likely to lead to an increase in the vulnerability of many sensitive environments and that this vulnerability may be exacerbated by increased visitor pressure as a result of warmer, drier weather. This effect is likely to be most noticeable at coastal sites where increases in popularity, combined with potentially reduced land area due to sea level rise and increased erosion, can deplete the resource itself and thus impact on habitats and species such as shore bird populations via increased disturbance and reduction in available space.

Longer, warmer and drier summers may result in more people visiting the outdoors over an extended 'season', and bring with it increases in pressure on available recreation and access resources. Greater use of path networks will put more pressure on surfaces and increase subsequent erosion risk, which, combined with greater use of associated access furniture (i.e. gates, stiles, bridges etc.), will put more pressure on maintenance regimes and budgets.

Higher temperatures and an increased incidence of drought are likely to result in the drying-out of vegetation and increase the risk of wildfires, particularly in vulnerable areas of grass and heathland which also attract a lot of visitors. Wild fires will impact on species and habitats (as discussed elsewhere in this manual), and the increased risk of wildfires could lead to more frequent closures of open access land. Public rights of way are not affected by access land restrictions, but permissive paths may be shut.

Desiccation of soils during hot, dry periods may lead to soil loss and subsequently result in damage to unsealed path surfaces, particularly if combined with stronger winds.

Warmer, drier conditions could lead to increased use of coastal areas, with greater numbers visiting coastal resorts and beaches (Coombes, Jones & Sutherland 2009; de Freitas 1990) and a corresponding increase in water-based activities (Simpson 2013). Increased visitor numbers will potentially put pressure on associated habitats such as sand dunes and coastal marshes, with potential increases in disturbance and trampling. An increase in water-based recreation may impact on coastal and marine sites, with disturbance to seabird and marine mammal populations (Natural England 2012).

Inland, visits to rivers, lakes and reservoirs may increase, with similar pressures on associated recreational infrastructure and adjacent habitats. However, reduced water levels may prevent the use of some water bodies (Defra 2014) and lead to more pressure on unaffected sites. A reduction in precipitation may also lead, directly and indirectly, to an increased risk of eutrophication and the development algal blooms developing in inland water systems with associated health risks to recreational users. (Note - this may also be a consequence of higher winter precipitation and/or summer storms (Defra 2104)).

A longer annual growing season may result in greater vegetation growth, with paths and access areas becoming more overgrown and needing more frequent cutting/weed control from relevant managers and landowners (Scottish Natural Heritage 2011). Grazing regimes may also need to change, this may also affect access, especially for people with dogs. This may deter people from using some public rights of way, with consequences for people's health, enjoyment and local visitor economies, and could put pressure on available management budgets.

Higher winter rainfall

Increased precipitation and associated run-off could lead to saturated soils and associated flooding and erosion of path surfaces (Scottish Natural Heritage 2011). Where material has been eroded from surfaces, paths could become more difficult and dangerous to use and the repair of damaged paths will put additional pressure on managing authorities' maintenance and repair regimes. Physical loss of paths and associated infrastructure will reduce the availability of path networks and may reduce tourism income, which could be felt particularly in areas where walking and riding are important to the local economy. Erosion will also lead to the deposition of eroded material elsewhere, which could necessitate its removal from other areas. Erosion of path networks may also have subsequent impacts on surrounding protected sites as people divert around waterlogged areas or inadvertently create more erosion within fragile habitats.

Erosion of coastal or riverside routes can result in the complete loss of a path since public rights of way are fixed to a specified, legal route. Consequently, unless a suitable alternative route can be found or a new route created, both of which could be expensive to implement, the network could be permanently depleted.

Upland routes, especially those on steep slopes and with fragile soils, and where there is intense visitor pressure, are particularly vulnerable to erosion damage because of the generally high levels of precipitation (rain and snow) they experience. The potential for erosion will increase if overall precipitation, or the intensity of precipitation, increases. This will have implications for management and maintenance. However, warmer winters may also result in fewer freeze-thaw cycles (which are more significant in upland areas), which may mean less erosion from frost heave.

Milder winter periods may also serve to extend existing visit/recreational activity beyond the 'traditional' activity periods, which in turn could lead to more constant visitor pressure on routes and areas. However, this could also serve to even out visitor pressure over the course of a year. When combined, more visits during the period when water levels are at field capacity will result in increased wear of path surfaces resulting in more muddy paths, particularly in areas where users congregate at stiles and gates. This will vary according to soil type and underlying geology and hydrology.

More frequent extreme weather events

Distinct events such as heatwaves, flooding and drought are predicted to become more severe due to climate change and will potentially bring increasing challenges for recreation management since the scale and unpredictability of such events makes them more challenging to plan for and manage than more expected seasonal events.

More frequent and intense storms are likely to increase the risk of wind damage to routes and sites, with fallen trees and other debris needing to be cleared if paths and spaces become obstructed or dangerous for public use. Extreme and unpredictable weather events could also present a safety hazard for visitors, particularly in exposed, upland and coastal areas, and additional work could be needed to ensure the safety of structures such as bridges and walkways where these are provided as a visitor management measure e.g. on nature reserves, promoted routes etc. These less predictable events will inevitably make it challenging for access managers to plan ahead.

Rising sea levels, coupled with more frequent storm events will exacerbate coastal erosion, potentially resulting in shoreline retreat and loss of beaches. Coastal routes may be damaged and, if they do not have the capacity to vary or roll back, may be permanently lost or made unsafe, necessitating repair or replacement. An increased risk of rock-falls on eroding cliffs will also have safety implications for beach users and for activities such as rock climbing and coasteering. More frequent, and perhaps more widespread, inundation of lower lying areas as a result of storm surges will create similar issues to other forms of flooding and could result in permanent land use change and potentially loss of access due to erosion/infrastructure damage.

More frequent extreme flood events in general will, like more seasonal flooding, cause physical damage to routes and areas as well as interruptions to network use via inundation and subsequent waterlogging, but the scale and unpredictability of occurrence will exacerbate their effect. Caving systems are susceptible to seasonal and periodic flooding, depending on a system's hydrological characteristics and rainfall events. More precipitation in general may make some caves less accessible, and more frequent heavier rainfall events may increase the incidence of flash flooding and the obvious risks to cavers/visitors associated with this.

Similarly, extreme droughts and heatwaves will mirror the general risks associated with hotter, drier summers, such as higher fire risk and the desiccation of surfaces, but more acute conditions and the unpredictability of such events will exacerbate their impact.

Extreme heatwaves increase the risk of associated health issues such as heatstroke and respiratory problems related to increased pollution levels. This will have implications for health services provision, but will also affect people's decisions and behaviours about where to go and what to do. Perry (in Hall (2005) p86) observes that: 'For many sporting and leisure activities there are critical thresholds beyond which participation and enjoyment levels fall and safety or health are endangered.' Perry also noted that in the European heatwave of 2003, extreme heat levels led to a range of behaviours including tourists abandoning planned visits, but also more people in urban areas going to the countryside to try and escape higher heat and pollution levels.

Location and physical characteristics

The vulnerability of a site or route to the impacts of climate change will vary according to its location and physical characteristics.

The landscape and topography within which a recreational route or area is located will influence its exposure and vulnerability to the impacts of climate change. For example, paths and areas in the uplands will tend to experience more extreme weather, and will often be located on steeper slopes and thinner soils. Consequently, they are likely to be more vulnerable to the effects of weathering and erosion than those in lowland areas. Low-lying areas may be more susceptible to waterlogging and flooding, and routes and areas on the coast will be more at risk from coastal flooding and erosion associated with sea level rise.

Local physical features along the length of a route or within an area will also be important.

These include:

- the degree of slope along a path - longitudinally and in cross-section;
- the amount of shading by vegetation along a route, which can affect rainfall interception and exposure to other weathering agents;

- the amount and type of surface vegetation cover. This will influence the cohesion of the surface, runoff characteristics and susceptibility to precipitation, desiccation and frost action.
- The proximity and hydrological behaviour of wetland features such as rivers, streams and marshes/bogs will influence how much of a route or area is susceptible to waterlogging or erosion.
- The severity of weathering and erosion to a route or site will also be influenced by the composition of the surface material and its underlying soil type.

Surfaces will have varying degrees of soil exposure depending on whether they are sealed or unsealed and how well consolidated or permeable the substrate is. Many paths will have some form of drainage such as parallel ditches, cross-drains and culverts, depending on the level of management and their susceptibility to waterlogging. Where drainage can be managed, the risk of surface degradation, flooding and erosion may be reduced.

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Public access, biodiversity and climate change

Most nature reserves, and many other sites of high biodiversity value, will have a degree of public access, depending on their location, ownership, management objectives and legal obligations. Many sites, including Natural England's National Nature Reserves, RSPB reserves and many Wildlife Trust sites, are actively managed for both wildlife and visitors, while others may be managed primarily for conservation or some other purpose, but will nonetheless have some form of public access via public rights of way, open access land, paid for or permissive access arrangements.

The potential effects of climate change on habitats and species are discussed elsewhere in this manual. In many cases, these impacts will bring management challenges, and these challenges are likely to be compounded if climate change results in significantly increased visitor pressure or changes in visitor behaviour.

Natural England's Recreation and Disturbance Theme Plan (Natural England, 2015a), compiled as part of the Improvement Programme for England's Natura 2000 Sites (IPENS), noted that recreation patterns were likely to alter with changing climatic factors such as higher temperatures and more rainfall, and observed that,

'The disturbance effects of public access may also alter as a result of climate change on some sites. For example, where coastal squeeze is causing a reduction in the area of habitat available for some features (such as is being seen with nesting habitat for little terns), disturbance effects may increase even if the number of people using a site does not change. This can be because use of the site may be concentrated in a reduced area.' (p11)

Climate change may also increase the number of invasive species which can persist in the UK and movement of people is one of the ways some of these spread. For example, the **Pirri-pirri bur** has been identified as being easily spread through attachment to human clothing and would benefit from a warmer climate (GB Non-Native Species Secretariat 2015).

The effects of climate change on habitats and species can be predicted and planned for to a certain extent, but changes in people's behaviours and actions in response to climate change are more difficult to predict, especially in relation to specific sites.

The Natural England **Monitor of Engagement with the Natural Environment** summary reports for years 1- 4 included data on motivations and barriers to accessing the natural environment. While weather seems to be a factor influencing people's use of the natural environment, it is more likely to be a contributory factor compared to other influences so it is difficult to say with confidence how people's behaviours will change in response to a changing climate, when thinking about specific sites. McEvoy *et al* (2008) note that 'the relationship between climate and visitor demand is complicated', and that 'climate influence on visitor behaviour is more likely to be overshadowed by socio-economic trends'. However, there seems to be confidence that if higher summer temperatures become more common, then this will lead to increased visitor levels, particularly at the coast, and more participation in marine/coastal based activities such as beach visits and water-sports (Coombes, Jones & Sutherland 2009).

Balancing the needs of visitors and the management of protected sites and species within the context of a changing climate will clearly present a range of management challenges if the benefits of recreation and the necessity of protecting the conserved resource are to be realised. This will rely on informed management practices based on good evidence and the flexibility to apply that management on a site basis.

Potential adaptation responses

This section provides an overview of some of the main issues in adapting recreation routes and sites to climate change. Adopting resilient designs and being flexible to developing conditions when planning new provision or adapting existing resources will be a key approach to adapting to future demands.

Design and materials

The behaviour of a route surface in response to natural and human weathering agents is critical to its resilience. The choice of materials, whether the surface is sealed or unsealed, profile design and camber, and construction methods, will be important considerations when planning new paths or for the maintenance and repair of the existing network, in response to predicted levels of use and changing environmental factors.

Choosing resilient materials and designs may incur higher costs but these will need to be considered alongside long-term performance and resilience in response to changing conditions. The use of boardwalks or flexible bonded surfaces, for example, may be the best option for areas likely to be permanently or frequently wet. The choice of materials used will also be a consideration however, as other environmental impacts, e.g. micro-plastics in the environment, will have to be considered.

Drainage

The performance of any associated drainage is vital in the creation and maintenance of path networks, and planning resilient drainage will clearly benefit from a good knowledge of local hydrological characteristics of a site or area. Knowledge can be gained from observing the previous behaviour of a site or route's drainage under varying conditions, seeking advice from authorities or organisations that manage access in areas that see higher rainfall and/or more extreme weather events (e.g. upland areas), and obtaining expert assessments through hydrological surveys and modelling.

As well as assessing the effects of rainfall and flooding on routes themselves, the hydrological impact of a path or path network on local flood management may have to be taken into account since there is evidence to suggest that paths can accelerate water transfer downslope and exacerbate flooding (Cumbria Floods Partnership 2016).

Designing for resilience should aim to build in the capacity to cope with both current and projected future levels of precipitation and run-off, to provide, as far as possible, a buffer to cope with greater volumes of water and more frequent rainfall and storm events. This may often involve simply creating larger and more numerous drains and culverts, and using more robust materials. It may also be possible to design footpath drainage to have a beneficial impact on adjacent biodiversity, i.e. diverting water in to green infrastructure beneficial for biodiversity (See chapter 4).

Access furniture

Structures such as stiles, gates and benches are vulnerable to damage from flooding and fire, and foot/bridle bridges in particular are often in the front line during flood events. When planning for new provision or replacing existing structures in vulnerable areas, adopting more resilient designs and materials will help to increase overall resiliency of the resource.

For example, increasing the span or height of foot path and bridle path bridges can enable them to withstand periodic high flows, (e.g. SUSTRANS 2015 Ch 8; Scottish Natural Heritage 2011), but larger structures can be very costly to install. Moving structures to less vulnerable locations may also be possible.

Route location

Although re-routing a footpath or bridleway may be a pragmatic response where it is at risk, most access networks will comprise public rights of way, and any change to their route would entail going through a legal process to obtain a diversion or closure, or in the case of National Trails, a variation process requiring approval by the Secretary of State for the Environment. This can be impractical, expensive and time consuming. However, if long-term resilience is dependent on relocating part of a route, for example away from a watercourse or stretch of coastline that is vulnerable to erosion or flooding, then this should be considered.

As has been noted above, the England Coast Path can adapt via its roll-back provision and identifying optional alternative routes when the 'ordinary' route may be unavailable due to erosion, flooding etc.

A certain amount of network loss will be inevitable as paths are either destroyed completely, or prove impractical or too expensive to protect or move. However, accepting this and allowing natural processes to take their course, can allow landscapes to develop naturally and, if it is an option for access managers, working with these processes means that benefits and savings may still be realised without compromising overall public benefit. Clearly there will be a difference here between definitive routes where there is a duty to keep them open and usable and permissive or non-definitive routes needing no legal mechanism to close or divert them.

Adaptation to flooding could involve:

- Diverting or closing rights of way if they are lost or become unusable.
- Use of seasonal Traffic Regulation Orders to adapt to waterlogging/flood conditions.
- Use of voluntary restrictions to access during impassable/recovery conditions.
- Provision of targeted recreational information and education about areas and times to avoid visiting when flooded or at risk of being flooded.
- Identifying more resilient routes within a vulnerable area and negotiating alternative/ new permissive and/or statutory access.

Management and maintenance regimes

Maintenance regimes will necessarily have to adapt to changing climatic impacts. The nature of the work involved and the frequency of those works will need to reflect changing environmental demands, for example more frequent cutting of encroaching and surface vegetation, and more regular inspections of path surfaces and drainage.

Scottish Natural Heritage observes that, 'In common with other aspects of the 'transport network', the key issue for adapting to climate change is effective maintenance. Therefore regular (which may or may not be frequent) small- scale maintenance is likely to arrest the deterioration of paths that would be susceptible to the 'magnified' effects of the climate compared with current conditions – i.e. helping the path to cope with chronic effects. Where it becomes apparent that particular features or sections are failing repeatedly the option should be taken to re-evaluate the specification rather than replace / repair like-for-like.' (Scottish Natural Heritage 2011 p27).

Statutory provisions for adaptation

In some instances, adaptation for access and recreation will involve a statutory process, or will be underpinned by legislation. Examples of statutory provisions relevant to climate change adaptation include:

Changes to public rights of way

As mentioned above, relocating a public right of way may be considered where public use and enjoyment is threatened, and while the legal process is often costly and time consuming it will usually be preferable to losing a route altogether. There may also be opportunities to create or dedicate new routes and considering future climate change resiliency, whilst not a statutory requirement in current highways will be advisable in planning future provision. Such changes could be planned as part of a Rights of Way Improvement Plan (ROWIP) – see section on ROWIPs below.

SSSI diversion orders

SSSI diversion orders are now a provision under the 1980 Highways Act, and allow certain public rights of way to be re-routed where on-going use of a right of way is causing damage to the features of the protected site. Climate change may intensify potential conflicts between public access and nature conservation, and therefore conservation bodies and access authorities should be aware of the potential for using SSSI diversion orders for securing both conservation and public access benefits. Further information on the use of SSSI diversion orders can be obtained from Natural England.

England Coast Path roll-back

The England Coast Path is a long-distance National Trail which will, when completed in 2020, gives people a right of access around the entire English coast. The Coastal Access Scheme includes a 'roll back' provision, so that if a section of coast erodes the path can be moved progressively inland (without lengthy referral processes) and also has the option, where appropriate, of identifying alternative routes. The ability to move the route of the path in response to shifting coastlines ensures that a measure of climate change resilience is being built into its design. As noted previously, other public rights of way do not enjoy this provision and where they succumb to coastal or river bank erosion they can be lost for good. The England Coast Path is included as a case study later in this chapter.

Countryside and Rights of Way act (CROW) restrictions on open access land and the England Coast Path

Under the provisions of the CROW Act, landowners can apply to relevant authorities (Natural England, the Forestry Commission and the National Park authorities) to close land for the purposes of land management, nature conservation, fire prevention, or public safety. Natural England has published **guidance** on the use of such restrictions. These provisions are potentially helpful in responding to some climate change impacts, particularly in times of drought where the risk of wild fire is high, or where continued public access would pose a risk to wildlife. Because open access land often coincides with areas of high biodiversity value, these areas can be vulnerable to excessive visitor pressure. Guidance for land owners responsible for managing **Open Access Land** and the **England Coast Path** has been published by Natural England (2014, 2015b).

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Rights of Way Improvement Plans (ROWIPs)

ROWIPs are strategic documents drawn up by highways authorities as a requirement of the Countryside and Rights of Way Act 2000. They aim to assess and improve an authority's rights of way network and are required to be reviewed at no more than 10 year intervals. They are usually linked to the relevant Local Transport Plan (LTP), which sets rights of way within the context of an area's wider transport network.

The impacts of climate change are now an important factor to be considered in the maintenance and development of an authority's rights of way network and should be an integral part of any planned improvements. The renewal of a ROWIP is a good opportunity to include an assessment of, or make provision for an assessment of, climate change, particularly since ROWIPs and LTPs can work over long time frames.

Considerations could include:

- Assessing the current public rights of way network for climate change vulnerability and changes since the last ROWIP, and assessing risks as above.
- Identifying the impact of climate change on users' enjoyment of the network and how recreational behaviours may be affected by a changing climate, for example increasing usage and greater demands on the network.
- Ensuring that new provision is, as far as possible, future-proofed for a changing climate.

Local Access Forums (LAFs) also have a key role in monitoring local public rights of way and providing input to ROWIPs and ROWIP reviews, and could usefully consider the impact of climate change on their areas.

Summary of potential adaptation options

Climate change impact	Potential adaptation options	Possible issues
Waterlogging and erosion of path surfaces	■ Use existing techniques and standards for path drainage, but higher specifications may need to be used and maintenance regimes for the clearance of ditches and culverts etc. may need to be revised. ■ Adopt more resilient surfacing materials and construction techniques. ■ Re-model path profiles to encourage better drainage. ■ Use England Coast Path (ECP) roll-back and optional alternative routes. ■ Where possible, reposition paths to minimise waterlogging and erosion. ■ Install larger drains/culverts to cope with potentially large scale and longer-term water-logging events. ■ Install boardwalks if drainage is impractical in wetter areas, or if drainage is not possible without damaging areas of important wetland habitat. ■ Manage visitors to divert them away from sensitive areas, either temporarily or longer term. ■ Targeted tree/shrub planting to help reduce erosion/runoff e.g. upslope from vulnerable paths. ■ Incorporate water management and biodiversity gain in adaptation actions where appropriate.	■ Any improvements to drainage or new drainage infrastructure affecting SSSIs or protected species are likely to need consent. ■ **Note**: the surface of a public right of way (PROW) is generally not considered part of a protected site unless a specific feature, for example a stand of vegetation has been designated on or across it. ■ A PROW may require legal diversion if it becomes unusable, and may require a SSSI diversion order if a protected site is affected. ■ Planting and biodiversity gain will need to be considered in the context of wider land management and conservation targets and designations to increase effectiveness and identify any conflicts of interest.
More frequent flooding	■ Undertake more frequent maintenance and/or maintain to a higher specification, for example resurfacing paths and clearing debris from surfaces. ■ Increase maintenance or specification requirements for watercourses and flood-banks where routes and recreation areas cannot be relocated. ■ Working with natural processes, allow room for landscapes to change and evolve more naturally, and plan the repositioning of routes and other recreation facilities as the landscape develops. ■ When replacing footpath and bridle path bridges, adopt more resilient designs, for example with open lattice to allow freer water flow and/or higher and wider spans to withstand periodic high flows. ■ It may be possible to negotiate temporary, permissive alternative routes with landowners, or for new rights of ways to be dedicated permanently.	■ Increased surface maintenance and the need for resurfacing will place extra demands on budgets and on the available workforce. ■ Enhancing flood management infrastructure will place additional pressure on funding sources, and new resources may need to be secured. This may be difficult to justify when resources are limited, and when there may be clear conservation arguments for allowing rivers and their flood plains to operate more naturally in times of flood. ■ Diverting a PROW can be time consuming and expensive, and may not be possible, in which case the route may be lost permanently. ■ Adopting a 'roll-back' approach may be possible for the ECP, but is not usually an option for public rights of way.
Increased coastal flooding and erosion	■ Use the roll-back provision where possible (i.e. for the England Coast Path) and identify optional alternative routes where appropriate. ■ Managed realignment to restore or create intertidal habitat schemes at the coast should incorporate relocation of access routes and the creation of new access opportunities.	■ On rapidly eroding coasts, the implications for available funding and staff time could be significant

Climate change impact	Potential adaptation options	Possible issues
Increase in probability and severity of wildfire risk (see Peak District National Park case study)	■ CROW open access land restrictions can be used to reduce the risk of fire and potential danger to visitors. The relevant authority can make restrictions during exceptional conditions as identified via the Fire Severity Index (FSI). ■ The public can be encouraged to identify and report fire outbreaks via leaflets, posters and other informative material.	■ CROW restrictions do not affect public rights of way
Damage and disturbance to habitats/species caused by higher visitor numbers	■ Ensure that visitor management plans for sites and areas identify and address climate change impacts. ■ Develop, promote and maintain visitor routes and venues to reduce potential pressure on sensitive sites. ■ Use on site visitor management techniques to improve the visitor experience in non-sensitive areas. ■ Develop educational and interpretive resources to influence visitor behaviour and explain why management actions such as closing access to sensitive sites or asking people to use different routes is necessary. ■ Open Access land and the England Coast Path (ECP) have mechanisms for assessing access impacts on protected sites, e.g. the **Access and Sensitive Features Assessment Process (ASFA)** (Natural England 2017b) for the ECP. ■ SSSI diversion orders may be used where use of a right of way is causing damage to the special features of a SSSI.	■ The SSSI diversion order process requires that Traffic Regulation Orders are used in the first instance and that an acceptable alternative route has been identified.
Increased pressure on access infrastructure by higher visitor numbers.	■ It may be possible to reduce impacts by adopting more resilient designs/standards, and by managing visitors to spread pressures between different sites and path networks.	■ The ability to adapt may be limited by budgets and staff resources, or by a lack of alternative routes or sites.

Approaches to risk assessment and strategic planning for access and recreation

Identifying the risks from climate change and planning suitable adaptation responses is increasingly acknowledged as a requirement for all access and outdoor recreation resources. The general approach to identifying and responding to risks is similar to that for managing habitats and species covered elsewhere in this manual.

Ignoring the impacts of climate change is generally not a viable option since it could lead to a loss of public amenity, non-compliance with statutory duties, and potentially greater overall costs in the long term. Available resources will determine how much can be done, but it is important to systematically identify and consider potential impacts in order to plan for their current and future management.

Adaptation planning for recreation will generally follow a clear planning cycle. Scottish Natural Heritage (SNH) (Scottish Natural Heritage 2011) recommend six stages:

1. **Identify vulnerabilities**. Identify the acute and chronic impacts and pressures on access resources.

2. **Carry out a risk assessment**. What level of risk do the identified impacts represent, with risk being a function of the probability of the event occurring and the magnitude of its impact. High probability, high impact events will be at the high risk end of the scale and low impact, low probability events at the other.

3. **Generate risk management options**. The risk assessment process informs the selection of management options, i.e. reducing risk to a manageable level and/or taking opportunities to manage existing risk better.

   SNH identify four main generic options:

   - Business as usual - maintain and construct to existing best practice.
   - Future proof designs - construct to higher specifications or in different locations.
   - Retro-fit solutions - improve resilience by adapting existing infrastructure.
   - Develop contingency plans - e.g. re-construct key infrastructure, or downgrade or abandon paths or structures where it is no longer viable to maintain them.

4. **Carry out a cost benefit analysis**. Identifying the costs and benefits of different management options is important and can be valuable in making a case for funding. Budgets for access management can be limited, but opportunities can occur. For example, the Cumbria Countryside Access Fund (see case study), which was established following the 2015 floods, has focussed on the economic and social benefits that public use of the path network can bring.

5. **Implement chosen options.** Once a decision has been made and resources identified, a programme of action tailored to the site or area involved can be rolled-out.

6. **Monitor and review**. Monitoring and reviewing the effect of any actions taken will be vital for future adaptation planning. Being able to be respond to changing environmental conditions, as well as changes in visitor behaviour, will give any management programme essential flexibility.

The more detailed the assessment of climate change risks then the more data will be available for asset management (e.g. by carrying out or commissioning professional hydrological or geomorphological assessments). Rights of way and other access resource managers will often have direct, practical experience of dealing with the effects of changing weather conditions and will have experienced changes first hand, which should also be taken in to account in assessments.

Scottish Natural Heritage (2011) noted that adequate design, good practice and construction standards already exist for paths to cope with long-term physical conditions, and that future-proofing for climate change adaptation and resilience relies on ‘planned, preventative maintenance’. The knowledge and best practice to work with and manage the effects of climate change on recreational networks is often already there, and many managers have the front-line experience and skills needed to pass these on to others.

Case studies

Building resilience following the Lake District floods of 2007, 2009 and 2015

Cumbria and English Lake District suffered devastating floods in late 2009 and again, as a result of Storm Desmond, in the winter of 2015. These events followed previous extreme flooding events in 2005 and 2007. The events severely affected communities; flooding people's homes, destroying infrastructure and inundating farmland. The visitor economy, the Lake District's main revenue source, was also severely affected.

A significant part of that economy is the outdoor sport, education and recreation sector, which in Cumbria for example employs over 5000 people in 400 businesses, and contributes around £250 million a year to the area's economy (Cumbria Vision 2009).

Storm damage on Cat Bells footpath. © Jessie Binns, National Trust

Both the 2009 and 2015 flood events had a major impact on the region's public rights of way network which, along with the extensive areas of access land, provides the main infrastructure for recreational activities. In both cases, the recovery programmes were prioritised using criteria relating to the protection and benefit of: local communities, the visitor economy, protected sites and climate change resilience.

The impacts of the events comprise acute impacts directly related to the events, i.e. destruction of infrastructure and inundation of networks, but will also have exacerbated longer term, chronic climate effects. Rainfall is one of the key factors in determining the scale of footpath erosion, which is primarily influenced by three factors: water (rainfall intensity), variation in path gradient (slope) and recreational pressure (trampling) (McEvoy *et al* 2008).

In 2009, there were 319 separate damage reports within the Lake District National Park (LDNP) public rights of way network, with an estimated £4 million of damage incurred (**Cumbria Floods 2009 GOV.UK Incident Report**) (Cumbria County Council 2010). This damage consisted mainly of destroyed, or badly eroded, paths and damaged access furniture, (e.g. lost footbridges, signs, gates and stiles). 253 bridges were lost, 85 public paths had surfaces severely damaged and 70 had destroyed access furniture (**LDNP ROWIP delivery report 2009/10**) (Lake District National Park). Grants of £250,000 towards repair of the damage were secured from Defra in 2009/10 and 2010/11 (**LDNP ROWIP delivery report 2009/10**) (Lake District National Park). Similar resources were made available following flood events in 2013/14 for the Broads, Exmoor, Dartmoor, North York Moors and Yorkshire Dales National Parks, each of which received a share of £400k for recreational infrastructure repairs (**.GOV press release 2014**) (UK Government 2014)

In 2015, within the LDNP, 562 kms of public rights of way were affected by the floods, generating a repair bill of £5.8 million and severely compromising access resources for visitors, communities and the local economy.

The Cumbria Countryside Access Fund was set up following the 2015 floods. £3 million was allocated to the LDNP, with a further £500k going to Cumbria County Council and the Canals and Rivers Trust. The LDNP will use the resources from the fund to help their resulting 'Routes to Resilience' (Lake District National Park 2017) programme.

Damaged bridleway ford and footbridge at Townend © Natural England/A Mackintosh

The funds priorities are:

- rights of way that lead to or connect rural towns and villages, visitor attractions or assets
- multi-user and long distance trails
- rights of way that pass through environmentally sensitive areas such as Sites of Special Scientific Interest
- Proposals for funded works also had to demonstrate that climate change resilience was taken into account in any proposed works, for example by using improved surface materials for paths and using flood resilient designs for bridges. The project ended in February 2019 and had restored 94 bridges, 65 public paths and 44 items of access furniture.

Repaired section of Cat Bells path with improved drainage culvert. © Natural England/A Mackintosh

The England Coast Path near Minehead, Somerset. © Natural England/A Mackintosh

England Coast Path, building in flexibility

Coastal erosion to roads and footpaths in the East Riding of Yorkshire. © Natural England/A Mackintosh

Public Rights of Way are tied to a legally determined fixed route. If the physical route is lost through erosion, for example along a river bank or on an eroding stretch of coast, the legal rights of access associated with the route are also lost. Creating a permanent alternative route will usually involve a statutory diversion or creation order, which can take time and is not always possible to achieve.

The England Coast Path (ECP), which is being implemented by Natural England under provisions of the Marine and Coastal Access Act 2009, adopts a different, more flexible approach. Where NE proposed roll back as part of its alignment proposals and where these proposals have been approved by the Secretary of State, the ECP can be moved back in land on the coast without any further approval from the Secretary of State. Roll back can happen for example where significant coastal erosion or physical change occurs due to geomorphological processes such as landslips, or where there is significant encroachment by the sea as a result of a natural or deliberate breach of existing sea defences. Natural England's (2013) **Coastal Access Scheme** sets out the methodology for implementing the coast path route and the associated coastal margin.

Once a stretch of coastline has been assessed, a report is submitted to the Secretary of State recommending the alignment of the route, the extent of the coastal margin to be established either side of the route, and any specific management measures necessary for example: for the protection of vulnerable sites or species. If approved by the Secretary of State, the new access rights along the relevant stretch of coast are brought into effect by Order.

A list of grounds for providing a direction to restrict access are detailed in Chapter 6 of the Coastal Access Scheme and include: fire prevention, nature conservation, land management and public safety; all of which provide potential options for visitor management necessitated by climate change impacts.

The effect of roll-back, and options for alternative routing and restrictions, gives the ECP a degree of flexibility to respond to the impacts of climate change. This flexibility is particularly useful on rapidly eroding coasts, and over time the experience of implementing and managing roll-back should provide useful insights into how to manage public access on the coast in response to a changing climate.

Moorland wildfire risk management

Wildfire Baildon Moor West Yorkshire. © Natural England/Dave Key

As noted previously, hotter, drier summers are one predicted outcome of climate change bringing with it a higher risk of summer wildfires via high temperature, drier conditions and greater potential fuel sources. Furthermore, Albersten *et al* (2010), with reference to the Peak District moorlands, also note that the likelihood of spring wildfires is not necessarily reduced by wetter winters. They also note that, in addition to biophysical fire hazards, recreation provides a 'major ignition source' - via either intentional or accidental fire starting – and that hotter, drier conditions may lead to an increase in total visitor numbers and/or a concentration of visits on warmer drier periods thereby increasing that risk. However, this risk can potentially be mitigated by increased awareness of the risk and effects of wildfires as well as management measure such as creating firebreaks and/or removing potential fuel.

Wildfires result in vegetation damage and species loss and, with many upland habitats, including heath and blanket bog, being areas of high biodiversity value (and protected sites under UK and European legislation), these are clearly major conservation concerns.

Increased wildfire risk will also impact on the availability of public access; particularly for users of access land which can be closed in the event of high fire risk. Hotter, drier weather may also lead to an increased demand for shadier routes, e.g. in woodlands, or routes nearer lakes or reservoirs, and greater visitor numbers generally will put more pressure on available visitor resources and infrastructure.

Authorities and organisations who are responsible for and manage areas of high wildfire risk obviously need to take these risks into account when planning and implementing biodiversity and visitor management strategies.

Evidence and Strategic planning. The **Peak District National Park** state 'The Since 1976 there have been over 350 reported incidents of 'wildfires' of which the majority are commonly started by arson, discarded cigarettes, barbeques and campfires.' In response to this ongoing risk **The Peak District Fire Operations Group** (FOG) was formed to co-ordinate fire-fighting resources and currently includes serving fire officers and land and recreation managers,

Fire plans have been put in place for moorland areas in the Peak District and South Pennine Moors and wildfire risk maps produced to inform wildfire response planning. Data from fire records and ranger observations/logs have been used to map and produce models predicting where fires are most likely to occur. A vulnerability score was derived for identified habitat types, based on the number of actual past fires relative to the number expected in each area, and additional human and physical data layers applied to build the risk maps. It was also identified that ignition risk increases closer to access points (Walker *et al* Moors for the Future Partnership 2009 and McEvoy *et al* 2008).

Visitor engagement. Actions can include providing information to raise awareness about the risks of wildfire and engaging with the public and local communities to help with fire prevention and encourage better reporting of wildfires.

The main messages that local authorities and bodies such as **Moors for the Future** want to convey to the public are:

- The extreme vulnerability of the moorland in dry conditions.
- The most likely causes of fire, particularly smoking and the use of matches.
- The severe environmental damage to moorland caused by fire.
- Appealing for help in preventing and reporting fires

Access management. Access Authorities as defined by the Countryside and Rights of Way (CROW) Act 2000, are responsible for closing access land in response to fire risk. The decision to close moorland is determined by the '**Meteorological Office Fire Severity Index**', which has 5 levels. The right of access under the CROW Act is suspended when the level reaches 5, but public rights of way, as highways, are unaffected by this legislation and remain open.

Another option in tackling wildfire management is the use of **Public Space Protection Orders** (PSPO's) under the Anti-social Behaviour, Crime and Policing Act 2014. In 2019 Bradford Council introduced a **PSPO** prohibiting the use of barbeques, fires, fireworks, Chinese lanterns etc. within defined areas covering the popular Ilkley, Baildon and 'Bronte' moors near Howarth in West Yorkshire.

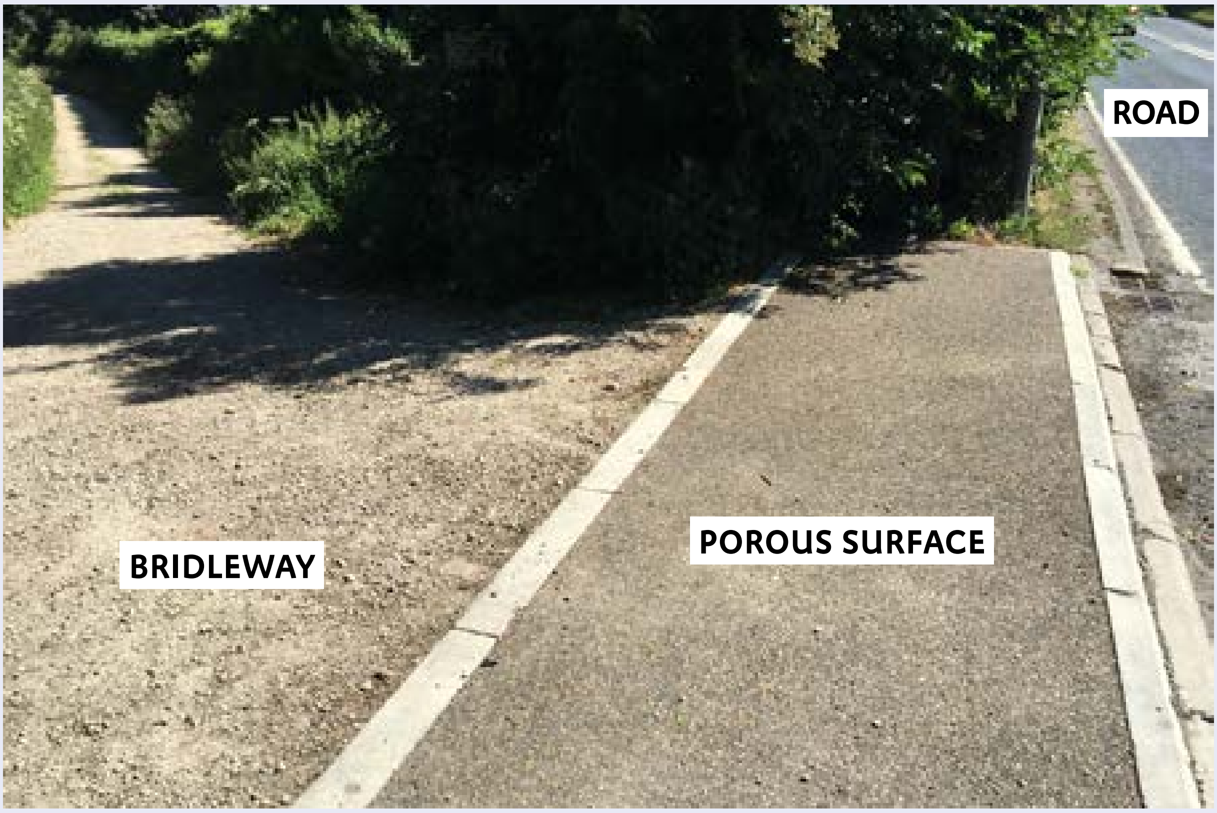
West Yorkshire/Leeds 2015 flooding

The 2015 Boxing Day flood had an unprecedented impact on West Yorkshire when up to 13 cm fell of rain fell on saturated ground causing multiple flooding events throughout the region, and particularly in the Upper Calder Valley and Leeds City Region. An estimated £500 million of damage ensued, affecting homes and businesses, and causing extensive infrastructure damage.

Access resources and networks were affected by erosion of path surfaces, loss of associated infrastructure and damage to drainage systems etc. Subsequent repair works, funded by partnerships between local authorities, SUSTRANS, Groundwork Leeds and the Canals and Rivers Trust, and from central government and the European Regional Development Fund, have ranged from relatively small scale adaptation works on individual paths, to large scale infrastructure replacement which, in some places, has provided an opportunity to incorporate public access improvements into flood defence and mitigation work.

East Keswick bridleway adaptation

Excessive runoff from the rainfall event was funnelled by asphalted roads towards a junction with the bridleway. The kerb was over-topped and the bridleway then provided a steep drainage route downslope towards the River Wharfe. The existing drainage ditch could not cope with the excessive water and the bridleway was badly eroded along its length with the resultant gullying making it unsafe and unusable for riding.



East Keswick Bridleway. © Natural England/A Mackintosh with thanks to R Brookes, Leeds City Council

The junction was identified as a vulnerable point for future flood risk events and the entrance to the right of way, which is also used by farm traffic, was adapted to be more resilient. The path was resurfaced and, at the junction, underground rainfall storage chambers were installed beneath porous surfacing with an overflow pipe directed into an improved drainage ditch.

Trans Pennine Trail, Leeds

The Trans-Pennine Trail (SUSTRANS Route 66) is a major coast-to-coast multi-user route, with a particularly popular section through Leeds used extensively for commuting and recreation.

The trail was damaged during the flooding and was affected by subsequent major infrastructure work connected with the Leeds Flood Alleviation Scheme (Leeds City Council 2016). Large scale infrastructure adaptation has included an innovative movable weir at Knostrop (below), flood walls, embankments, and the merging of the river and canal to increase water storage. The works entailed re-routing the trail, and the opportunity was taken to upgrade parts of the route and provide a new bridge over the weir.

Knostrop weir and Trans Pennine Trail bridge. © Natural England/A Mackintosh

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- **Upland Path Management: Standards for delivering path projects in Scotland's mountains**.
- **Constructed tracks in the Scottish Uplands**.
- **Path Bridges: Planning, Design, Construction and Maintenance**.

SUSTRANS: **Traffic-free routes and greenways design guide**.

Part 7

Ecosystem Services and climate change

Introduction

The natural environment, its landscapes, habitats and biodiversity provide ecosystem services to people - benefits to society that are often under-noticed and undervalued. Four broad categories of ecosystem services are now widely recognised: supporting, provisioning, regulating, and cultural. These are provided through a mix of biological, ecological, physical and chemical agents and processes.

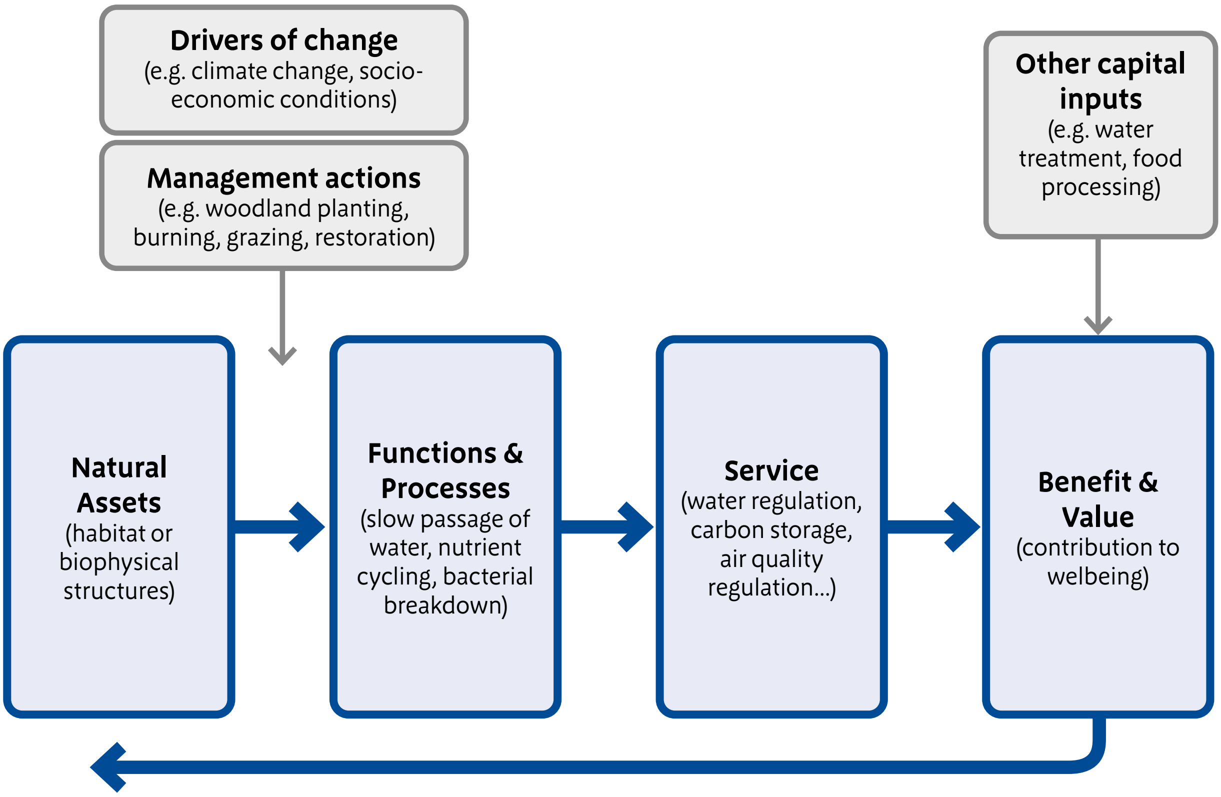
As climate change affects the natural environment, this will impact on the ecosystem services the environment provides. Maintaining these services to people and society can be a powerful lever to secure interest in, and resources for, adaptation of the natural world.

This section provides a brief analysis of the potential impact of climate change on the provision of ecosystem services and potential adaptation responses to this. This analysis is drawn principally from the **United Kingdom National Ecosystem Assessment** (UK NEA 2011), which provides an overview of the state of UK ecosystems, the services they provide, and the key drivers of change, including climate change.

An ecosystem is 'a dynamic complex of plant animal and micro-organism communities and their non-living environment interacting as a functional unit' (Millennium Ecosystem Assessment MA 2005). The UK NEA uses the Broad Habitat types from the Countryside Survey as the basis for its classification of ecosystems. Ecosystems, or habitats, and the ecosystem processes that occur through the interactions of their biotic and abiotic components, provide the basic infrastructure of life. These underpin the supporting services: the capture of energy from the sun (primary production), the formation of soil, and the cycling of water and nutrients. These are required for the production of all the other provisioning, regulating and cultural ecosystem services. Factors such as climate change, which result in changes to ecological processes and the supporting services, affect all the other services which they support. The relationship between habitats, soils and underlying landforms (natural assets), ecosystem processes and the resulting benefits to people (ecosystem services) is commonly illustrated as the ecosystem services cascade (see below).

This section does not provide a detailed analysis of the impact of climate change on individual ecosystem services. Instead, it draws out the links between habitats, ecological processes and ecosystem service provision, and considers how climate change is likely to impact on the processes of primary production, soil formation and nutrient and water cycling (the supporting services).

Recognising that many adaptation responses for biodiversity will also address these important life support services, it signposts those habitats that are important for delivery of particular services. It does not provide detail on the impact on provisioning, regulating or cultural services. However, through the summary of the impacts of climate change on the supporting services, it aims to aid consideration of the resulting impacts on the other ecosystem services.



The ecosystem services cascade (modified from Haines Young and Potschin 2010)

Habitats and the provision of ecosystem services

As shown in the ecosystem services cascade, the continued provision of ecosystem services is dependent on a series of ecosystem functions that are defined by the nature and quality of habitats. The table below identifies which habitats are particularly important for the provision of particular ecosystem services and identifies the relevant habitat sheets. The assessment of the relative importance of Broad Habitats for delivering ecosystem services is taken from the UK (NEA) Synthesis Report. The UK NEA Technical Report, Broad Habitat chapters, provides more detail on the provision of ecosystem services by habitats. Some ecosystem services are not just habitat specific, but are also strongly location specific depending on where the service is 'produced' relative to the people who benefit. This makes it difficult to develop generic rules about habitat-ecosystem service relationships that can be applied in all circumstances. The table below should therefore be interpreted in the context of local knowledge.

Service Group	Ecosystem Service	Broad habitats considered to be of high or medium to high importance in the provision of each ecosystem service (excluding marine and urban habitats)	Relevant habitat sheets
Provisioning	Crops	Enclosed farmland	Traditional orchards
	Livestock/ aquaculture	Enclosed farmland	Hedgerows and walls
	Fish	Freshwaters – open waters, wetlands and floodplains	Rivers and streams Standing water Lowland fen Reedbed
		Coastal margins	Coastal saltmarsh Coastal floodplain grazing marsh
	Trees, standing vegetation, peat (for timber, construction, fuel etc.)	Woodlands	Broadleaved mixed and yew woodlands Woodpasture and parkland
		Mountains, Moorlands and Heaths	Upland heath Lowland heath Montane habitats Blanket bog
		Enclosed farmland	Hedgerows Traditional orchards
		Freshwaters – open waters, wetlands and floodplains	Lowland fen Reedbed
	Water supply	Mountains, Moorlands and Heaths	Upland heath Lowland heath Blanket bog Upland flushes, fens and swamps
		Freshwaters – open waters, wetlands and floodplains	Rivers and streams Standing water Lowland fen Reedbed
Cultural	Wild Species Diversity Environmental settings: landscapes/ seascapes and local places	Mountains, Moorlands and Heaths	Upland heath Lowland heath Montane habitats Blanket bog Upland flushes, fens and swamps
		Semi-natural grasslands	Lowland dry grassland Upland acid grassland Calcareous grassland Lowland meadow Upland hay meadow Purple moor grass and rush pasture
		Woodlands	Broadleaved mixed and yew woodlands Woodpasture and parkland
		Freshwaters – open waters, wetlands and floodplains	Rivers and streams Standing water Lowland fen Reedbed
		Coastal Margins	Coastal saltmarsh Coastal sand dunes Coastal vegetated shingle habitat Coastal floodplain grazing marsh
		Enclosed farmland	Arable field margins Hedgerows Traditional orchards

Service Group	Ecosystem Service	Broad habitats considered to be of high or medium to high importance in the provision of each ecosystem service (excluding marine and urban habitats)	Relevant habitat sheets
Regulating	Climate (includes greenhouse gas regulation and local micro-climate effects e.g. cooling from urban trees)	Mountains, Moorlands and Heaths	Upland heath Lowland heath Blanket bog Upland flushes, fens and swamps
		Semi-natural grasslands	Acid grassland Calcareous grassland Lowland meadow Upland hay meadow Purple moor grass and rush pasture
		Woodlands	Broadleaved mixed and yew woodlands Woodpasture and parkland
		Coastal Margins	Coastal saltmarsh Coastal sand dunes Coastal floodplain grazing marsh
	Hazard (e.g. regulation of soil erosion, flood risk, landslides, river and coastal erosion)	Mountains, Moorlands and Heaths	Upland heath Lowland heath Montane habitats Blanket bog Upland flushes, fens and swamps
		Semi-natural grasslands	Lowland dry acid grassland Upland acid grassland Calcareous grassland Lowland meadow Upland hay meadow Purple moor grass and rush pasture
		Enclosed farmland	Arable field margins Hedgerows
		Woodlands	Broadleaved mixed and yew woodlands Wood pasture and parkland
		Freshwaters – open waters, wetlands and floodplains	Rivers and streams Standing water Lowland fen Reedbed Lowland raised bog
		Coastal Margins	Coastal saltmarsh Coastal sand dunes Coastal floodplain grazing marsh
	Disease and pests	Enclosed farmland	Arable field margins Hedgerows Traditional orchards
		Freshwaters – open waters, wetlands and floodplains	Rivers and streams Standing water Lowland fen Reedbed
	Pollination	Semi-natural grasslands	Lowland dry acid grassland Upland acid grassland Calcareous grassland Lowland meadow Upland hay meadow Purple moor grass and rush pasture
		Enclosed farmland	Arable field margins Hedgerows Traditional orchards
	Noise	Woodlands	Broadleaved mixed and yew woodlands Woodpasture and parkland
		Coastal Margins	Coastal saltmarsh Coastal sand dunes Coastal floodplain grazing marsh

Service Group	Ecosystem Service	Broad habitats considered to be of high or medium to high importance in the provision of each ecosystem service (excluding marine and urban habitats)	Relevant habitat sheets
Regulating	Water Quality	Mountains, Moorlands and Heaths	Upland heath Lowland heath Montane habitats Blanket bog Upland flushes, fens and swamps
		Semi-natural grasslands	Lowland dry acid grassland Upland acid grassland Calcareous grassland and limestone pavement Lowland meadow Upland hay meadow Purple moor grass and rush pasture
		Enclosed farmland	Arable field margins Hedgerows
		Woodlands	Broadleaved mixed and yew woodlands Woodpasture and parkland
		Freshwaters – open waters, wetlands and floodplains	Rivers and streams Standing water Lowland fen Reedbed Lowland raised bog
		Coastal Margins	Coastal saltmarsh Coastal sand dunes Coastal floodplain grazing marsh
	Soil Quality	Mountains, Moorlands and Heaths	Upland heath Lowland heath Montane habitats Blanket bog Upland flushes, fens and swamps
		Semi-natural grasslands	Acid grassland Calcareous grassland Lowland meadow Upland hay meadow Purple moor grass and rush pasture
		Enclosed farmland	Arable field margins Hedgerows and walls Traditional orchards
		Woodlands	Broadleaved mixed and yew woodlands Woodpasture and parkland
		Freshwaters – open waters, wetlands and floodplains	Rivers and streams Standing water Lowland fen Reedbed Lowland raised bog
	Air Quality	Semi-natural grasslands	Lowland dry acid grassland Upland acid grassland Calcareous grassland and limestone pavement Lowland meadow Upland hay meadow Purple moor grass and rush pasture
		Enclosed farmland	Arable field margins Hedgerows Traditional orchards
		Woodlands	Broadleaved mixed and yew woodlands Wood pasture and parkland

Adapted from UK NEA Synthesis Report Figure 5 and Technical Report Table 2.1.

Potential climate change impacts on supporting services

The impact of climate change on ecosystem services is principally through changes to biogeochemical and physical processes within ecosystems, as well as through impacts on biodiversity which may provide ecosystem services (e.g. materials, pollination, physical structures, tourism). These changes affect the supporting services, resulting in impacts on the other provisioning, regulating and cultural services they underpin. This section provides a brief analysis of how climate change impacts on the supporting services of primary production, soil formation, nutrient cycling and water cycling, and the potential effects of these changes on other ecosystem services. This structure is intended to guide readers through an analysis of the likely impacts on ecosystem services and help link to adaptation responses described elsewhere in this manual.

There is much uncertainty about how climate change will impact on the supporting services, particularly on nutrient cycling and primary productivity. The impacts on supporting services are also interconnected; for example, changes in nutrient and water availability affects rates of primary production, which in turn affects nutrient and water cycles. The impacts are highly complex and responses to one aspect of climate change (e.g. drought) may be countered by responses to another (e.g. elevated carbon dioxide) or management responses (e.g. irrigation). As an example, primary production is expected to increase with higher temperatures and increasing levels of atmospheric CO_2. However, water availability and soil nutrient supplies may limit this.

The focus on these four supporting services does not address the impact of climate change on disease and pests, with an increase in the prevalence of non-native species, pests and pathogens predicted. It also does not adequately consider changes in biodiversity in terms of the diversity of different levels within food chains and the impact of this on broader services. The impact of climate change on cultural services is particularly uncertain. We do not know the relationship between current habitat condition and cultural services, let alone how climate change will impact on this relationship. We have addressed some of these impacts in this second edition of this manual, including recreation and access. We intend to address other aspects such as the historic environment and landscape character in future editions of this manual.

The table below is based on the supporting services chapter of the UK NEA (UK NEA Chapter 13 Supporting Services) and its evidence base.

Cause	Consequence	Potential impacts on supporting services	Provisioning, Regulatory and Cultural services affected
Increased frequency of storms and intense rainfall events	Altered coastal and freshwater dynamics and morphology. Increased erosion. Tree and other plant damage.	**The water cycle** Increase in the frequency and intensity of peak flows and tidal surges. Changes in sediment dynamics - increased sediment loads, changes in geomorphology. **Nutrient cycling** Increased leaching of nutrients and increased nutrient run-off. Increased flux of carbon (both dissolved and particulate). Changes in soil microbial activity with water logging. **Soil formation** Loss of soils due to erosion. Loss of organic matter due to leaching. **Primary production** Loss of and damage to standing timber, crops and vegetation.	**Provisioning** Crops/livestock/aquaculture (e.g. soil erosion, flood damage). Trees, standing vegetation and peat (e.g. wind throw of trees). **Cultural** Wild species diversity (e.g. loss of coastal and freshwater habitat, loss of species sensitive to high nutrient levels). Environmental settings (e.g. changes in landscapes with erosion, deposition and flood damage). Recreation (e.g. footpath erosion and closures). **Regulating** Climate (e.g. erosion and dissoluton of stored carbon in soils). Hazard (e.g. landslides, increased flood risk). Water quality (e.g. increased nutrient and sediment loads).
Sea Level Rise	Increased erosion. Saline intrusion. Anthropogenic intervention, such as hard sea defences.	**The water cycle** Changes in the extent of tidal influence. Changes in the location of the boundary between freshwater and sea water. **Nutrient cycling** Changes in location of the interface between freshwater and sea water, affecting the habitats present, geomorphological processes, and nutrient cycling. **Soil formation** Brackish water encroachment on low lying land and soil salinisation (Orford and Pethick 2006). Disturbance of coastal landforms, habitats and soils, with change in rates of erosion, sediment transport and accretion, steepening, and landslide activity on susceptible coasts. Coastal squeeze of habitats not able to move further landward due to hard defences. **Primary Production** Brackish water encroachment on lowland coastal areas affecting primary productivity. Changes in the location of the boundary between freshwater and sea water, and associated changes in species distribution and nutrient supply. Loss of soil due to erosion.	**Provisioning** Crops (e.g. agricultural land loss due to erosion). Livestock/aquaculture (eg risk to livestock of increased coastal flooding). Trees, standing vegetation and peat (e.g. affected by salination of soils). Water supply (e.g. saline intrusion of groundwater). **Cultural** Wild species diversity (e.g. loss of coastal and freshwater habitat). Environmental settings and recreation (e.g. loss of beaches and dunes). Historic environment (eg erosion of coastal archaeological sites). **Regulating** Climate (e.g. changes in stored carbon in soils). Hazard (eg increased flooding, landslips). Water quality (e.g. saline intrusion). Soil quality (e.g. salination of soils).

Cause	Consequence	Potential impacts on supporting services	Provisioning, Regulatory and Cultural services affected
Increased annual average temperatures Hotter summers	Increased evapo-transpiration. Increased rate of biogeochemical processes. Longer growing season. Fewer winter frosts. Changes in crop and timber species. Increased risk of wildfires. Increase in the prevalence of invasive non-native species, pests and pathogens.	**Water cycle** Decreases in soil moisture. Changes in river flow regimes, contributing to low flows. Changes in sediment erosion, transport and accretion. Changes in evapotranspiration with changes in crop species. **Nutrient cycling** Changes in the abundance and activity of soil organisms/microbes. Increased rates of soil weathering. Increased rate of decomposition of soil organic matter. Changes in plant growth and the composition of vegetation communities, affecting the activity of soil organisms/microbes. Increases in ammonia emissions and methane fluxes, with increased soil temperature. Changes in denitrification and increased rates of nitrate loss from rivers and lakes (Whitehead *et al* 2009). Increased phytoplankton growth in freshwater, with associated algal blooms. Extended periods of temperature stratification in lakes and associated anoxia (lack of oxygen) at depth. **Soil formation** Changes in the abundance and activity of soil organisms/microbes. Increased rates of soil weathering. Increased rate of decomposition of soil organic matter and loss of soil carbon (Dorrepaal *et al* 2009). Reduction in the frequency of freeze/thaw cycles, which are important for montane soil formation. Changes in the composition of vegetation communities. Increased soil erosion by water, wind and human activity. **Primary production** Shifts in species distributions in terrestrial and freshwater habitats. Changes in the timing of seasonal events, migrations and food web interactions (Visser and Both 2005, Memmott *et al* 2007). Changes in soil microbial activity and nutrient cycling affecting plant nutrient supply and primary productivity (Bardgett *et al* 2008). Increased soil weathering and changes in the availability of nutrients. Increased phytoplankton growth in freshwater (with associated impacts on algal blooms and eutrophication). Changes in rates of plant growth.	**Provisioning** Crops (e.g. changes in crop selection). Livestock/aquaculture, fish (e.g. affected by low flows). Trees (e.g. changes in forestry productivity). Water supply (e.g. loss to evapotranspiration). **Cultural services** Wild species diversity (e.g. montane species no longer within climatic limits). Environmental settings, recreation (e.g. algal blooms affecting water-based activities). Historic environment (e.g. affected by changes in plant growth on archaeological sites). **Regulating** Climate (e.g. loss of stored carbon with wild fires). Hazard (e.g. changes in soil erosion with changes in soil formation). Disease and pests (e.g. increase in prevalence of pests and diseases, such as Lyme disease with increased tick survival in warmer winters). Pollination (e.g. bumblebee declines with climatic niche shifts (Williams *et al* 2007) changes in timing of flowering and the emergence of pollinators). Water quality (e.g. deterioration with increased concentrations of nutrients). Soil quality (e.g. with changes in soil formation). Air quality (e.g. increases in ammonia emissions).

Cause	Consequence	Potential impacts on supporting services	Provisioning, Regulatory and Cultural services affected
Drier summers	Increased frequency and duration of drought. Possible increases in visitor numbers in drier summers. Changes in the selection of crop species. Increased abstraction for irrigation. Increased competition for water resources. Increased risk of wildfires.	**Water cycle** Increased evapo-transpiration. Decreases in soil moisture. Low flows in rivers and reduced water levels in still waters, with loss of habitat complexity. Changes in sediment dynamics, sediment loads, and geomorphological processes. Changes in evapotranspiration with changes in selection of crop species. **Nutrient cycling** Changes in the abundance and activity of soil organisms/microbes. Changes in rates of soil weathering. Increased rate of oxidation and decomposition of soil organic matter, and loss of soil carbon. Changes in the composition of vegetation communities. Increased phytoplankton growth in freshwater, with associated algal blooms. Extended periods of stratification in lakes and associated anoxia (lack of oxygen) at depth due to reduced through-flow. Decreases in rate of leaching of nutrients. Potential for enhanced nutrient loss following drought periods, when plants have failed to make use of nutrients and fertiliser. **Soil formation** Changes in the abundance and activity of soil organisms/microbes. Increased rates of soil weathering. Increased rate of decomposition of soil organic matter and loss of soil carbon. Repeated summer droughts can have the cumulative effect of increasing soil carbon dioxide flux (Sowerby *et al* 2008 upland heathland). Oxidation of previously anaerobic peat soils, increased microbial activity and carbon loss (Freeman *et al* 2004). Changes in the composition of vegetation communities. **Primary production** Shifts in species distributions in terrestrial and freshwater habitats. Changes in soil microbial activity and plant nutrient supply. Changes in soil weathering, and plant nutrient supply. Increased phytoplankton growth in freshwater (with associated impacts on algal blooms and eutrophication). Changes in rates of plant growth. Desiccation/loss of vegetation.	**Provisioning** Crops/livestock (e.g. reduced crop yield). Aquaculture, fish (e.g. with low flows and deterioration in water quality). Trees, standing vegetation, peat, (e.g. reduced timber yield). Water supply (with low flows). **Cultural** Wild species diversity (e.g. affecting species intolerant of drought). Environmental settings (e.g. draw down on reservoirs). Recreation (e.g. water-based). **Regulating** Climate (e.g. loss of soil carbon). Water quality (e.g. increase in pollutant concentration). Soil quality (e.g. desiccation). Air quality (e.g. decreased removal of air pollutants by plants, as stomata are closed with low soil moisture levels).

Cause	Consequence	Potential impacts on supporting services	Provisioning, Regulatory and Cultural services affected
Wetter winters	Altered coastal and freshwater dynamics and morphology. Increased erosion. Increased risk of soil compaction and trampling/ mechanical damage.	**The water cycle** Increase in the frequency and intensity of peak river flows. Increased sediment loads in rivers and changes in river form.	**Provisioning** Crops (e.g. changes in crop productivity). Livestock (e.g. loss of grazing land due to water-logging). Aquaculture, fish (e.g. affected by increased sediment loads in rivers). Water supply (e.g. increases in water availability in winter). **Cultural** Wild species diversity (e.g. affecting species intolerant of water logging). Environmental settings (e.g. flood damage). **Regulating** Climate (e.g. with changes in soil organic matter and stored carbon). Hazard (e.g. increase in frequency of landslips). Disease and pests (e.g. increased risk of combined sewer overflow pollution). Water quality (e.g. with increased soil erosion). Soil quality (e.g. with increased surface run-off and leaching).
		Nutrient cycling Increased leaching of nutrients and increased nutrient run-off. Loss of organic matter and soil carbon due to leaching. Changes in soil microbial activity with water-logging. Water-logging of soils, resulting in increases in anaerobic conditions and changes to oxidation/ reduction processes. Soil compaction and loss of soil structure.	
		Soil formation Loss of soils due to erosion. Loss of organic matter and soil carbon due to leaching. Waterlogging of soils resulting in increases in anaerobic conditions and changes to oxidation/ reduction processes. Soil compaction and loss of soil structure.	
		Primary production Loss and damage of standing timber, crops and vegetation.	
Increased CO2	Increased CO_2 fertilisation.	**The water cycle** Changes in evapo-transpiration as a result of changes in plant growth and vegetation community composition.	**Provisioning** Crops, livestock, aquaculture, fish, trees, standing vegetation, peat, (e.g. affected by changes in plant growth). Water supply (e.g. potentially affected by changes in evapo-transpiration). **Cultural** Wild species diversity (affected by changes in composition of plant communities). **Regulating** Climate (with changes in rates of soil carbon sequestration). Soil quality (with changes in nutrient cycling and soil formation). Air quality (e.g. reduced uptake of ozone through plant stomata due to increased atmospheric CO2).
		Nutrient Cycling and Soil Formation Increased flux of carbon to plant roots and soil organisms/microbes (Bardgett *et al* 2008). Changes in plant growth and the composition of vegetation communities can affect the activity of soil organisms/microbes (Bardgett *et al* 2008). Changes in rates of soil carbon sequestration.	
		Primary production Increased plant photosynthesis and growth. Changes in the composition, diversity and primary productivity of vegetation communities. Changes in the energy flows, structure and function of food webs.	

Ecosystem Services - Adaptation responses

The concept of ecosystem services is an important component of the 'ecosystem approach', a framework for sustainable management of land and sea. A key element of the ecosystem approach is the management of ecosystems to ensure the delivery of multiple services and benefits. Adaptation to climate change is integral to the ecosystem approach as defined by the twelve ecosystem approach principles in The Convention on Biological Diversity (CBD Ecosystem Approach principle).

Those principles that are most relevant to climate change adaptation are:

Principle 5:

Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach

Ecosystem functioning and resilience depends on a dynamic relationship within species, among species and between species and their abiotic environment, as well as the physical and chemical interactions within the environment. The conservation and, where appropriate, restoration of these interactions and processes is of greater significance for the long-term maintenance of biological diversity than simply protection of species.

Principle 8:

Recognising the varying temporal scales and lag-effects that characterise ecosystem processes, objectives for ecosystem management should be set for the long term

Ecosystem processes are characterised by varying temporal scales and lag-effects. This inherently conflicts with the tendency of humans to favour short-term gains and immediate benefits over future ones.

Principle 9:

Management must recognise the change is inevitable

Ecosystems change, including species composition and population abundance. Hence, management should adapt to the changes. Apart from their inherent dynamics of change, ecosystems are beset by a complex of uncertainties and potential "surprises" in the human, biological and environmental realms. Traditional disturbance regimes may be important for ecosystem structure and functioning, and may need to be maintained or restored. The ecosystem approach must utilise adaptive management in order to anticipate and cater for such changes and events and should be cautious in making any decision that may foreclose options, but, at the same time, consider mitigating actions to cope with long-term changes such as climate change.

The delivery of multiple ecosystem services and benefits from a place is integral to the ecosystem approach. This delivery of multiple benefits is dependent on healthy, functioning, connected ecosystems, of a sufficient scale to enable the provision of the full range of ecosystem services, and that are able to adapt to the impacts of climate change. It is not possible to provide specific adaptation responses for multiple ecosystem services, as these will be locally specific. However, the habitat sheets suggest adaptation responses for priority habitats of importance in the provision of ecosystem services.

Further information

UK National Ecosystem Assessment

UK Climate Change Risk Assessment Evidence Report 2012

Key evidence documents

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Part 8

Glossary

Glossary

Adaptation – a change in natural or human systems in response to the impacts of climate change. These changes moderate harm or exploit beneficial opportunities and can be in response to actual or expected impacts.

Adaptive capacity – the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, take advantage of opportunities, or cope with the consequences. Adaptive capacity can be an inherent property of the system, i.e. it can be a spontaneous or autonomous response. Alternatively, adaptive capacity may depend upon policy, planning and design decisions carried out in response to, or in anticipation of, changes in climatic conditions.

Biodiversity Action Plan (BAP) – The UK Biodiversity Action Plan (UK BAP) is the UK Government's response to the 1992 Convention on Biological Diversity (CBD) and sets out action plans to aid recovery of the most threatened species and habitats.

Climate – the climate can be described simply as the 'average weather', typically looked at over a period of 30 years. It can include temperature, rainfall, snow cover, or any other weather characteristic.

Climate Change – this refers to a change in the state of the climate, which can be identified by changes in average climate characteristics which persist for an extended period, typically decades or longer.

Climate change scenario – a plausible description of the change in climate by a certain time in the future. These scenarios are developed using models of the Earth's climate, which are based upon scientific understanding of the way that the land, ocean and atmosphere interact and their responses to factors that can influence climate in the future, such as greenhouse gas emissions.

Climate envelope modelling – a technique for defining a species' tolerance to a changing climate, using statistical correlations between existing species' distributions and environmental variables.

Climate space – the geographical area which is suitable for a particular species, based on the climate parameters within which the species can survive and reproduce. Climate space does not take into account other factors, such as topography, food or water availability that might impact upon the species actual geographical range. As the climate changes, climate space will move, and species will need to track these movements to survive. This results in changes to species' local and regional distributions.

Climatic variables – these are surface variables such as temperature, precipitation, and wind.

Community composition – a group of species that coexist in space, interacting directly or indirectly.

Confidence – in a scientific context, confidence describes the extent to which the findings of an assessment are considered valid, based on the type, amount, quality, and consistency of evidence.

Connectivity – in an ecological context, connectivity is broadly the degree to which the landscape facilitates or impedes the movement of organisms between patches of habitat. The degree to which a landscape is connected influences the potential for organisms to move in response to climate change.

Ecological network – a suite of sites which collectively contain the diversity and area of habitat that are needed to support species and which have ecological connections between them.

Ecosystem – A dynamic complex of plant, animal, and microorganism communities and their non-living environment, interacting as a functional unit.

Ecosystem Services – the benefits to society from resources and processes provided by ecosystems. These can include pollination and disease control, food and fuel, regulating the flow of water through land to both prevent flooding and filter clean drinking water, and the aesthetic and amenity value of the landscape.

Eutrophication – a process whereby water bodies receive excess nutrients that can stimulate excessive plant growth, oxygen depletion and algal blooms.

Extreme weather – unusual, severe or unseasonal weather, or weather at the extremes of the range of weather seen in the past.

Greenhouse gases – a number of gases whose presence in the atmosphere traps energy radiated by the Earth, known as the greenhouse effect. These gases can be produced through natural or human processes. Carbon dioxide is the most important greenhouse gas. Other gases are methane, fluorinated gases, ozone and nitrous oxide.

Heterogeneity – the variety, relative abundance, and spatial configuration of geological, geochemical, physical and biological parameters found within an environment.

Impact – in the context of climate change, an effect of climate change on the environment. This may be detrimental or beneficial, and may be either as a direct consequence of climate change, or as a result of a human response to climate change.

Isostatic change – refers to the gradual rebound of land masses which had been forced down into the Earth’s mantle by the weight of ice sheets during the last Ice Age.

Landscape scale conservation – a term commonly used to refer to conservation action that covers a large spatial scale, usually addressing a range of ecosystem processes, conservation objectives and land uses.

Low regret adaptation options – options for which the implementation costs are low while, bearing in mind the uncertainties with future climate change projections, the benefits under future climate change may potentially be large.

Microclimate – the distinctive climate of a local area, whose weather variables, such as temperature, rainfall, wind or humidity, may be subtly different to the conditions prevailing over the area as a whole and from those that might be reasonably expected under certain types of pressure or cloud cover. Micro-climate will be influenced by environmental variables such as vegetation cover, aspect and proximity to water.

Mitigation – in the context of climate change, mitigation refers to efforts to reduce the extent of climate change by taking action to reduce greenhouse gas emissions and developing carbon sinks (stores of carbon that do not decompose to produce carbon dioxide).

Model – in its broadest sense, a model is a representation of how a system works and can be used to understand how the system will respond to inputs and other changes.

National Vegetation Classification (NVC) – a system of classifying natural habitat types in Great Britain according to the vegetation they contain. The NVC provides a systematic and comprehensive account of the vegetation types of the country, covering all natural, semi-natural and major artificial habitats in Great Britain.

No regret adaptation options – activities which would provide immediate economic and environmental benefits and continue to be worthwhile regardless of future climate. They would be justified under all plausible future scenarios, including without climate change.

Non-native species – a species living outside its native distribution range, which has arrived there by human activity, either deliberate or accidental. Non-native species can have a variety of effects on the local ecosystem. Where that effect is negative they are known as invasive.

Phenology – the study of periodic plant and animal life cycle events and how these are influenced by seasonal and inter-annual variations in climate. Examples include the date of emergence of leaves and flowers, the first flight of butterflies, the first appearance of migratory birds, the date of leaf fall in deciduous trees, and the dates of egg-laying of birds.

Projection – a plausible description of the future and the pathway that leads to it. Projections are not predictions. Projections include assumptions, for example, on future socio-economic and technological developments, which might or might not happen. They therefore come with some uncertainties.

Refugia – areas where micro-climatic or other local environmental conditions may enable a species or a community of species to survive after climate change has caused extinction in surrounding areas.

Resilience – describes the ability of a social or ecological system to absorb disturbances while retaining the same basic ways of functioning, and a capacity to adapt to stress and change.

Sensitivity – the degree to which a system is affected, either adversely or beneficially, by climate variability or change.

Sites of Special Scientific Interest (SSSI) – Nationally important sites designated by Natural England under the Wildlife and Countryside Act 1981 for being 'of special interest by reason of any of its flora, fauna, or geological or physiographical features'. Legislation and policy provides a high level of protection for these sites.

Special Areas of Conservation (SACs) – Protected sites designated under the Conservation (Natural Habitats, &c.) Regulations 1994 in transposition of the EU Habitats Directive. The Directive requires the establishment of a European network of high-quality conservation sites that will make a significant contribution to conserving the habitats and species identified in Annexes I and II of the Directive. Along with SPAs, these form the 'Natura 2000' series of sites. All terrestrial SACs are also designated as SSSIs.

Special Protection Areas (SPAs) – Protected sites designated under the Conservation (Natural Habitats, &c.) Regulations 1994 in transposition of the EU Birds Directive. The Directive requires the identification and classification of Special Protection Areas (SPAs) for rare or vulnerable species listed in Annex I of the Directive, as well as for all regularly occurring migratory species, paying particular attention to the protection of wetlands of international importance. Together with SACs, these form the 'Natura 2000' series of sites. All terrestrial SPAs are also designated as SSSIs.

Threshold – the magnitude or intensity that must be exceeded for a certain reaction, phenomenon, result, or condition to occur or be manifested.

Translocation – the deliberate movement of species' populations that are unable to move in response to climate change and would otherwise be 'stranded', to areas expected to be more suitable for their survival.

UKCP18 – The UK Climate Projections (UKCP18) are the most authoritative future projections of climate change for the UK, covering different time periods and a range of possible scenarios of greenhouse gas emissions.

Vulnerability – in this context, the degree to which an individual, environmental feature or a system is susceptible to the adverse effects of climate change. Vulnerability is influenced by the system's sensitivity and its adaptive capacity, as well as the magnitude of the change.

Weather – refers to the state of the atmosphere, across space and time, and includes temperature, cloudiness, rainfall, wind, and other meteorological conditions.

Front cover image:
Managed realignment at the RSPB's Titchwell reserve on the North Norfolk coast protects internationally important freshwater habitat, allows coastal habitats space to evolve and has also improved visitor facilities.
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