Climate Change Adaptation Manual

Evidence to support nature conservation in a changing climate

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Climate Change Adaptation Manual

Natural England and the RSPB

with the Environment Agency and the Forestry Commission

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1 Natural England, 2 RSPB, 3 Environment Agency, 4 Forestry Commission

Introduction

The need for climate change adaptation has become increasingly widely recognised in the last 20 years. Nature conservation was one of the first sectors to identify the need and to start developing approaches. To date, much of the focus has been 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.

Much of the work to date on adaptation in the natural environment has been centred on biodiversity, which is the focus for this first edition of the manual, particularly habitat management. However, this is a fast moving field and we anticipate the manual will be a resource that develops and grows over time. Subsequent revisions are intended to deal more thoroughly with species, and how managing the natural environment can help society to adapt to climate change. Other future topics include landscape character, geodiversity, and recreation. We encourage feedback and comment. The manual is designed to support practical adaptation, and the lessons learnt and experience gained will ideally be fed back as case studies to assist others.

This first edition of the adaptation manual is divided into three parts.

Part 1 provides background information and considers some of the key concepts that are widely recognised in developing adaptation. It contains sections on:

- Climate change and its impacts on the natural environment;
- The principles behind successful adaptation action;
- Vulnerability to climate change;
- The role of spatial scale in adaptation.

Part 2 consists of more detailed information on climate change impacts and potential adaptation responses for a range of habitats.

Part 3 considers the impacts of climate change on ecosystem services.

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 is being published in stages in 2013 and 2014. **The IPCC website** provides the entry point to a variety of reports. The latest conclusions on the physical science were summarised in a Summary for Policy Makers[1] in October 2013. 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". A second report on Impacts, Adaptation and Vulnerability was published in March 2014 and on mitigation in April 2014. In all casesthe Summary for Policy Makers is a good place to start.

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 2009**. This contains a wealth of information. A good place to start is the **summary of the Briefing Report**[2].

The maps, graphs and key findings within UKCP09 are the best way to see projected changes in the UK climate at a national and regional level. UKCP09 provides mapped projections of climate change at 25 km grid resolution, for climate variables such as temperature and precipitation, both seasonally and annually. Climate projections are available for three greenhouse gas emissions scenarios, seven 30-year time periods and a range of probability levels, to show the spread of possible outcomes. UKCP09 also provides maps of climate projections for the UK at different levels of global average temperature rise. This enables you to see, for example, what the 'safe' limit of a 2°C global increase, which may be with us around 2040, means for climate conditions here.

UKCP09 shows that the extent of change in our 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 projected climate change both over the next 20 to 30 years and over the course of the century; or looking at it another way, considering both the implications of a 'lower' level of climate change (2°C average global temperature increase) and more extreme changes (4°C global increase). This will help identify both immediate adaptation needs and the path of longer term changes 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 evapo-transpiration,

1 IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

2 Geoff Jenkins, James Murphy, David Sexton, Jason Lowe, Met Office Hadley Centre, Phil Jones, Climatic Research Unit, University of East Anglia, Chris Kilsby, University of Newcastle, UK Climate Projections: Briefing report, Version 2, December 2010

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.

UKCP09 also provides estimates that sea-level will rise between 30 and 46 cm between 1990 and 2095. Land movements mean that the actual sea-level rise will be higher than this in England, for example a central estimate of between 37 and 53 cm by 2095. The IPCC Fifth Assessment Report in 2013 shows increases in estimates levels of sea level rise, which have yet to be taken into account for UK coastal projections.

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 the IPCC Working Group 2** 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 **Climate Change Risk Assessment (2012)**[3].

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.

3 UK Climate Change Risk Assessment: Government Report January 2012

Flooding on the River Severn at Upton-upon-Severn

The effects of climate change on biodiversity have been the subject of many studies in recent decades, and impacts for some species are well documented. The Living with Environmental Change partnership has recently produced a Report Card on Terrestrial Biodiversity[4]. 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[5], which will be relevant to wetland habitats.

BOX 1

Headline messages from the UK Terrestrial Biodiversity Climate Change Impacts Report Card

- There is strong evidence that climate change is already affecting UK biodiversity. Impacts are expected to increase as the magnitude of climate change increases.
- Many species are occurring further north and at higher altitudes than in previous decades, including some species which have colonised parts of the UK from continental Europe.
- Recent rates of change in distributions differ between species. Some species, including many plants, are intrinsically slow to disperse and fragmentation of habitat may contribute to some species spreading more slowly than would be expected from climate change alone.
- Warmer springs in recent decades have caused a trend towards many biological events (eg flowering, budburst, laying and hatching of eggs) occurring earlier in the year. The rates of change vary among species, which may alter the interactions between species.
- There is evidence of changes in the composition of plant and animal communities, consistent with different responses of different species to rising temperature.
- Species differ in their responses to variation in precipitation. The effects of climate change are less certain for precipitation than for temperature, but potential changes could lead to substantial changes in biodiversity and ecosystems.
- Some habitats are particularly vulnerable to climate change. The risks are clearest for montane habitats (to increased temperature), wetlands (to changes in water availability) and coastal habitats (to sea-level rise).
- Climate change exacerbates the risk that non-native species (including pests and pathogens) may establish and spread.
- We expect there to be regional differences in the impact of climate change on biodiversity, reflecting different species, climate, soils and patterns of land use and management.
- The protected area network, which includes Sites of Special Scientific Interest and National Nature Reserves, will continue to have a valuable role in conservation, although there will be changes in populations, communities and ecosystems at individual sites.
- Climate change will interact with, and may exacerbate, the impact of other continuing pressures on biodiversity, such as land use change and pollution.
- Extreme weather events, such as droughts and floods, have clear impacts on ecosystems and the ecosystem services they provide. Climate change may alter the frequency and severity of such events. Extreme events associated with climate change may have a greater impact on biodiversity and ecosystems than changes in the 'mean climate'.

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 3 of the manual.

4 Morecroft, M. and Speakman, L (eds.) (2013).Terrestrial Biodiversity Climate Change Impacts Summary Report. Living With Environmental Change.
5 Watts G and Anderson M (eds.) (2013) A climate change report card for water. LWEC report card.

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**[6] 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).

6 HM Government. The National Adaptation Programme – Making the country resilient to a changing climate. July 2013

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

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

The concept of sustainable adaptation provides a useful way of looking at some of the prerequisites for a long-term, integrated approach to adaptation, including the synergies and trade-offs associated with cross-sectoral adaptation. Four principles for sustainable adaptation have been proposed (Macgregor and 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 2009** 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 the site is an essential prerequisite for this approach. Monitoring of 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 some adaptation measures, it is important to start adaption now.

Adaptation for the natural environment

There has been considerable effort to develop systematic, common approaches to climate change adaptation for the natural environment over the last ten years. Wildlife 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.

Within the UK, two influential documents have been published which propose adaptation principles; **Conserving biodiversity in a changing climate: guidance on building capacity to adapt**[7], produced by the UK Biodiversity Partnership, and the **England Biodiversity Strategy Climate Change Adaptation Principles**[8]. Approaches to adaptation have also been developed in a number of parallel areas, including geodiversity (eg Brown et al. 2012), **forestry**[9] and the **historic environment**[10].

The Government's **National Adaptation Programme** sets out 4 focal areas for adaptation in the natural environment.

- 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 landscape 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. Similarly, 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.

7 Defra (2007) Conserving biodiversity in a changing climate: guidance on building capacity to adapt
8 Defra (2008) England Biodiversity Strategy. Climate Change Adaptation Principles - Conserving biodiversity in a changing climate
9 Forestry Commission 2011 UK Forestry Standard Guidelines on Forests and Climate Change
10 English Heritage, 2008 Climate change and the historic environment

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. **Making Space for Nature**[11] (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[12]

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. 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 providing flood control 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.

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. Flood management and urban shading are well known examples. A good review of ecosystem - based adaptation can be found in Doswald & Osti (2011).

11 Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.A., Tew, T.E., Varley, J., & Wynne, G.R. (2010) *Making Space for Nature: a review of England's wildlife sites and ecological network*. Report to Defra.
12 Michael D. Morecroft, Humphrey Q. P. Crick, Simon J. Duffield, Nicholas A. Macgregor.
Resilience to climate change: translating principles into practice. Journal of Applied Ecology 2012, **49**, 547-551

4. Improving the evidence base

The evidence base on climate change and the natural environment has strengthened significantly in recent years and provides a sufficient basis for adaptation actions to start. There remain considerable uncertainties however, and, while these must be acknowledged in adaptation actions, they may also be reduced by research and practical experience. A **list of evidence gaps** was published alongside the LWEC climate change impacts report card for biodiversity. 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 evaluate the effectiveness of adaptation measures when they are introduced.

References

Macgregor & Cowan, C.E. 2011. Government action to promote sustainable adaptation by the agriculture and land management sector in England: in J.D. Ford & L. Berrang-Ford eds. Climate change adaptation in developed nations: from theory to practice. Netherlands: Springer.

N. Doswald and M. Osti (2011) **Ecosystem-based approaches to adaptation – good practice examples and lessons learned in Europe** Federal Agency for Nature Conservation, Bonn.

Eleanor J. Brown, Colin D. Prosser & Naomi M. Stevenson (2012). *Geodiversity, Conservation and Climate Change: Key Principles for Adaptation*. Scottish Geographical Journal, Vol 126: 234-239.

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

3. Assessing vulnerability to climate change

This section provides information on approaches that are being used to assess the vulnerability of conservation areas to climate change as a precursor to developing an adaptation strategy. It draws on methodology that has 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 conditions that could make things better or worse;
4. The capacity to manage those conditions.

These four factors and their inter-relationships are illustrated in figures 3.1 and 3.2.

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 to 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) could reduce resilience. 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 3.1 Factors to consider when assessing the likelihood of change

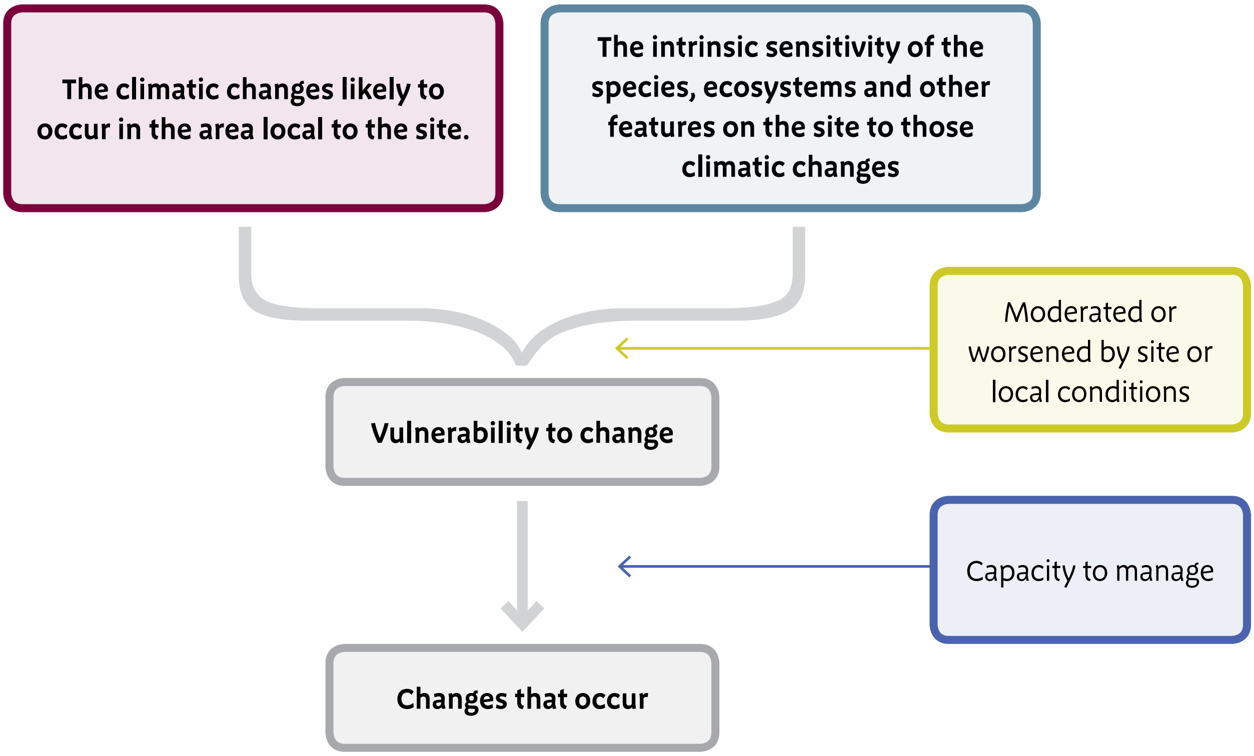

Figure 3.2 How these four factors determine the likelihood of change

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.
- Change will not always be harmful. When working with frameworks like the one above, there can be a tendency to focus on negative changes. However, climate change will bring a mix of threats and opportunities.

Sensitivity

Sensitivity is an important element of vulnerability and one in which some generalisations can be made at a national level, which are often a useful starting point for site-specific vulnerability assessments. Table 1 presents a basic classification of UK habitats according to their relative sensitivity to climate change. This is derived from a similar table originally published in **England Biodiversity Strategy - Towards adaptation to climate change**[13] and revised in the development of Natural England's **National biodiversity climate change vulnerability model**[14] and in producing this adaptation manual. The high sensitivity habitats are those whose existence is dependent on specific climatic, hydrological or coastal conditions, which projections indicate will change with climate change. The low sensitivity habitats are those which are determined by other factors such as grazing and geology, or with more generalist species, and where climate plays a minor role. It should be noted that these broad habitats include a wide range of vegetation types within them, and that these classifications are generalisations which should not be over-interpreted. It is also the case that the species' abundance and composition of low or medium sensitivity habitats may change even if the type of habitat remains broadly the same.

13. R.J. Mitchell[1], M.D. Morecroft[1], M. Acreman[1], H.Q.P. Crick[2], M. Frost [3], M.Harley[4], I.M.D. Maclean[2], O. Mountford[1], J. Piper[5], H. Pontier[6], M.M. Rehfisch[2], L.C. Ross[1], R. J. Smithers[7], A. Stott[6], C. Walmsley[8], O. Watts[9], E. Wilson[5]. England Biodiversity Strategy- Towards adaptation to climate change. Final Report to Defra for contract CR0327 May 2007

14 Natural England 2014. National Biodiversity Climate Change Vulnerability Model. Natural England Research Report NERR054

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.

These habitats are discussed in more detail in the individual habitat sheets contained in part 2 of the manual.

Species differ in their sensitivity to climate change. The reasons for this sensitivity vary and may be complex. In some cases, the limitations on a species' range are set by physical conditions, for example the failure to set viable seed at low temperatures. A classic example of this is the northern limit of the small leaved lime, *Tilia cordata*. In other cases, interactions with other species are the determining factor. For example, most alpine plant species can survive at higher temperatures than they typically occur at but do not do so in natural conditions because they cannot compete with taller, faster growing species typical of lower altitudes. Species may alternatively depend positively on the presence of another species, for example as a food source or host. Conservation adaptation actions may be able to address these issues, for example controlling competitors so reducing a species' vulnerability to climate change.

The relationship between many species' current range and climate implies that climate change will lead to changes in distribution. However, this needs to be interpreted with care as many other factors will influence a species' distribution, including the availability of habitat within the new climatically suitable areas, and the ability of a species to move. Nevertheless, as a general rule of thumb, a species at its northern range margin in Britain is likely to increase and spread further north, while one at its southern range margin is likely to decline and its geographic extent contract.

The relationship between a species' distribution and climate can be modelled using what are sometimes termed '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 future changes on the basis of climate change scenarios. This technique has been developed over the last twenty years in the UK, and projected changes in distribution are available for many species. One of the most influential projects of this sort in the UK was **MONARCH** (Modelling Natural Resource Responses to Climate Change). Another, which modelled a wide range of species in Britain, was **BRANCH** (Biodiversity Requires Adaptation in Northwest Europe under a Changing climate). Results from both of these projects continue to be valuable. Natural England also intends to publish a report on this topic using updated methodology in the next year. A similar approach has also been developed for woodlands through 'Ecological Site Classification', which models the future 'suitability' of NVC woodland types and individual species.

Climate envelope modelling has proved a very valuable guide to species sensitivity to climate change. It is useful in identifying where to prioritise action – for example in places where a species is likely to be at risk or to have an opportunity to colonise. However, it has limitations which need to be understood in using its results. These include the following:

- If current distributions are determined largely by factors other than climate, such as soil conditions associated with a particular local geology, the relationship between present day distribution and climate will be weak and of limited value in projecting future change. In the cases of rare, localised species, it will simply not be possible to derive any relationship to climate.
- Climate change may result in climatic conditions for which there is no present day analogue, and projections based on present climate will be unreliable.
- 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. So, 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 in more isolated areas and for harder to identify and less charismatic groups of species.
- Local climate variations and microclimates may provide conditions in which a species can survive locally, where one would not expect it to on the basis of larger scale patterns in climate. These localised areas of suitable climate are sometimes termed microclimatic refugia.
- Climate envelope models indicate where climate conditions may be suitable, but not whether a species can reach a new potential location or whether other requirements such as habitat or food supply will be available there.

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 above (fig 3.2). 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 (see fig 3.3 for an example output from the NBCCVM).

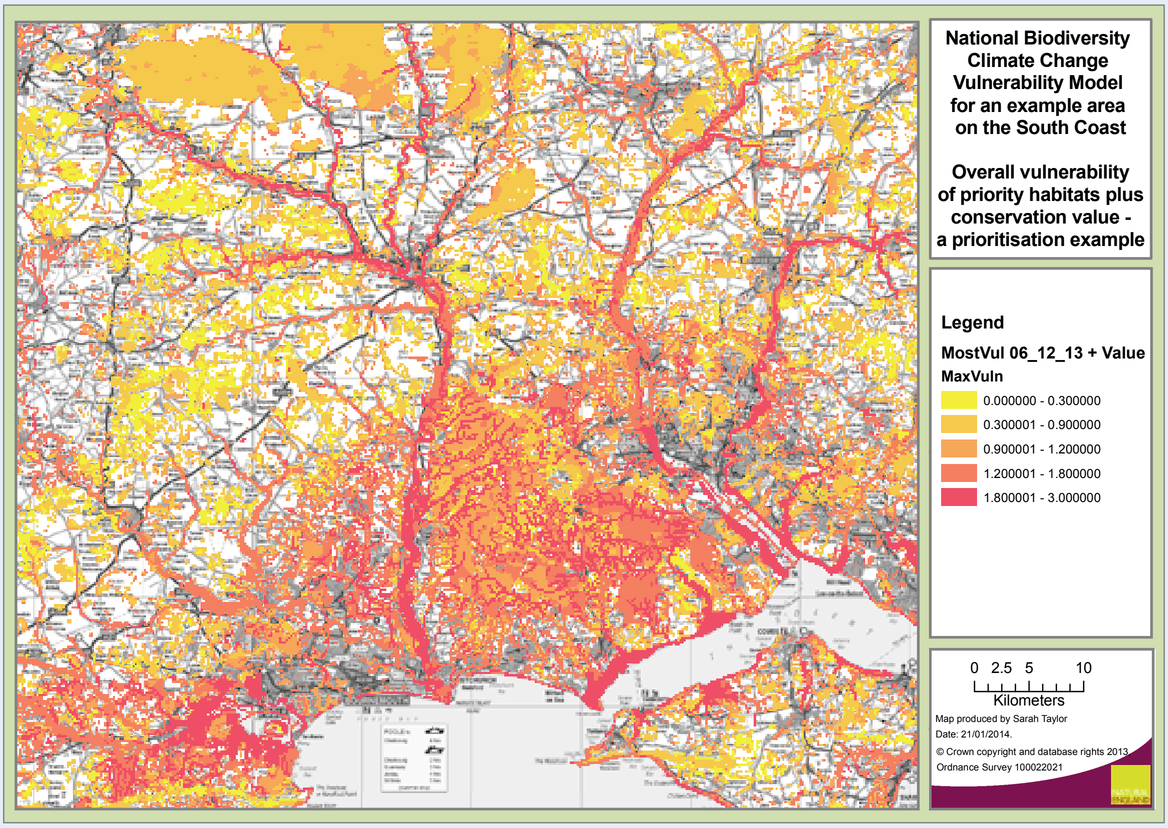

Fig 3.3

The example map in Figure 3.3 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**[15] on the development of the model. Further information about the model is also available **here**.

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

15 Natural England 2014. National Biodiversity Climate Change Vulnerability Model. Natural England Research Report NERR054

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**.

References and further reading

Glick G, Bruce A. Stein BA, and Edelson NA (eds) (2011) *Scanning the conservation horizon: a guide to climate change vulnerability assessment*. National Wildlife Federation. Washington DC.

Williams SE, Shoo LP, Isaac JL, Hoffmann AA, Langham G (2008) *Towards an integrated framework for assessing the vulnerability of species to climate change*. PLoS Biology 6, 2621-2626r.

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Warm, dry conditions will increase the risk of wildfires.

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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 it, rather than as a topic in its own right. The starting point in this case is 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, such as **Nature Improvement Areas**[16].

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 (eg 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 may 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 need 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 is developing its 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.

16 Natural England (2013) Assessing and enabling climate change adaptation in Nature Improvement Areas. Natural England Commissioned Report NECR119

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[17] 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 there are in the area, and are there any physical or functional relationships between them?
- whether 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.

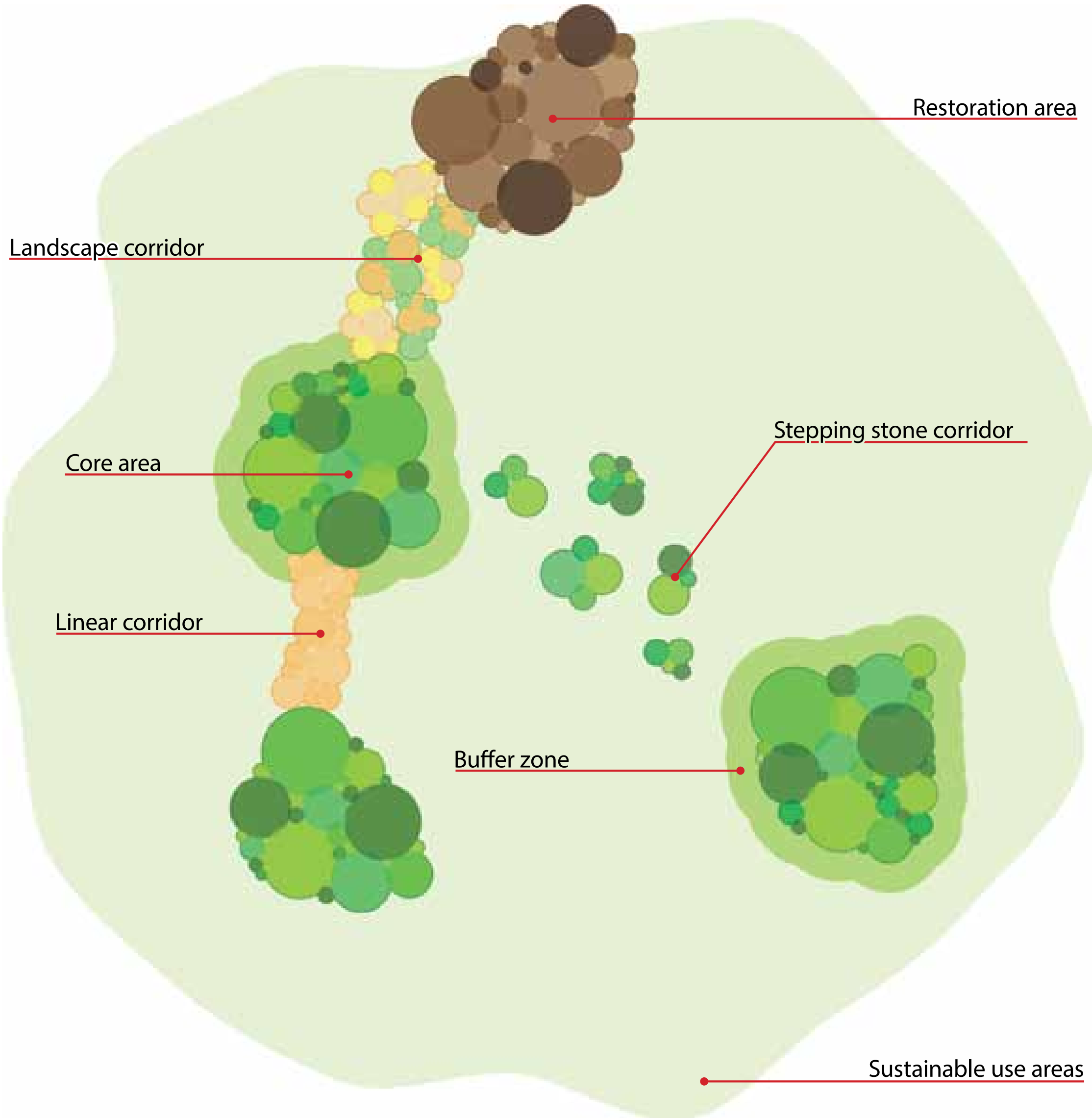
A key aspect of this wider approach is increasing the number of semi-natural habitat patches and making the surrounding farmed landscape more suitable for wildlife, thereby helping species to track their climatic requirements and disperse to new locations. This is described as increasing functional connectivity, 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.

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

17 Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.A., Tew, T.E., Varley, J., & Wynne, G.R. (2010) Making Space for Nature: a review of England's wildlife sites and ecological network. Report to Defra.

be the only way to ensure they reach potential new locations. 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 bio-diverse sites by providing a buffer, and in some cases by effectively increasing their size. These concepts are illustrated in Figure 4.1 below.

Figure 4.1 Approaches to improving functional connectivity



Adaptation can therefore be looked at from both ‘bottom up’ and ‘top down’ perspectives. The diagram below illustrates some of the questions that might need to be considered at different geographic scales.

Are rare or threatened species, landscape features or ecosystems likely to become more common elsewhere (or vice versa)? Does that affect priorities?	**Plan as part of a wider conservation strategy**	Is there a need to formally coordinate adaptation planning with other sites? It is important to consider the wider context for the site and any cross- administrative boundary issues.
What are the current movements of species or ecological processes such as hydrology across the site boundaries? Are there any pressures from outside the site? How might these change? Is the conservation area (whether formal reserve or not) big enough to support species populations? [An important question to consider but impossible to answer with certainty]	**Consider land use, landscape characteristics and ecological processes outside the site**	What options are there to influence land use, landscape and ecological processes outside the site, in order to increase the area of high quality habitat, link patches of high quality habitat together (especially those containing different microclimates), or buffer areas? Are there opportunities to provide ecosystem services that will benefit both conservation and other sectors?
What species, ecological communities and ecosystems are on the site and of greatest conservation interest now, and what might they be in the future? How has the site been affected by past weather events? What future changes are projected?	**Site-specific adaptation**	What are your conservation goals? How much change are you willing to accept? What management options do you have?

Figure 4.2 Adaptation questions at different scales

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?

Rockland Broad, Norfolk

Part 2

Habitats

Introduction to the habitat sheets

This section of the manual considers the potential impacts of climate change on individual BAP 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 originally published in the England Biodiversity Strategy, and revised in the development of Natural England's national biodiversity climate change vulnerability model 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 Environmental Stewardship Options.** This highlights the most appropriate options that are available under the higher level scheme (HLS) of Environmental Stewardship. This scheme is due to be replaced by a new environmental land management scheme in 2015. At the time of publication, the options for the new scheme are still being developed, and will be added to future revisions of the manual. The HLS options will remain relevant to existing agreements, which will normally last for a period of 10 years from their start date. For the woodland habitats, woodland options for the new scheme are described, but these are dependent on submission and approval of the new Programme document.
- **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.

List of habitat sheets

Thorpe Wood, Peterborough, Cambridgeshire

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 (eg shallow, freely-draining soils and clay soils), particularly 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 squirrel 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 waterlogging.

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 and of 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 961,000Ha 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 (eg deer and 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-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 eg 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 (ie 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 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 20090).
- In southern regions and on south facing slopes, there may be less need for coppice systems to maintain southern or heat loving elements of the woodland system (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.
- Accept near native species as a component of semi-natural woodland beyond their current native range, eg 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, in non-designated sites, changes in species composition, including the

retention of non-native/exotic species, maybe 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.

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 semi-natural habitats, including native and near native species from outside their current natural range where these are likely to benefit from projected climate change.
- 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 sites objectives.
- Improve understanding of soil properties and heterogeneity across the site, including the requirement of individual species and how these may change as climate change progresses.

Broadleaved woodland in the New Forest

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Relevant Environmental Stewardship options

Maintenance of woodland (HC07)

Restoration of woodland (HC08)

The aim of these options is to maintain or restore farm woodlands to benefit wildlife and protect and strengthen the local landscape character. It is only appropriate where the woodlands are part of the farmed landscape.

Priority is given to woodlands with ancient semi-natural characteristics and sites with remnants of ancient semi-natural woodland such as planted ancient woodland sites (PAWS) and grazed woodland.

Relevant English woodland grant options

The majority of woodland grants available under the English Woodland Grant Scheme closed to new applicants before April 2014. The grants outlined below, as set out in England's next Rural Development Programme document will be available when the new scheme opens in 2015 and, in some cases during the 2014 transition period. Up to date information is available from the Forestry Commission's **Grants and Regulations** web-pages.

Woodland Infrastructure Grant (replacing the **Woodfuel Woodland Improvement Grant**).
This grant supports the sustainable production of wood by improving access to woodland for management and harvesting purposes. The grant will cover a proportion of the cost of work, and will not take account of the timber income that results.

Woodland Improvement Grants
Grants to fund the improvement in the quality of woodlands to achieve specific objectives, through either capital investments or five-year revenue payments. Current priorities are: bringing priority habitats into target condition; supporting priority species (particularly birds and red squirrels); PAWS restoration through gradual conversion; and improving climate resilience through conversion to continuous cover approaches to management.

Woodland Regeneration Grant
Woodland Regeneration Grant (WRG) contributes to the costs of making changes to the composition of woodland within the normal cycle of felling and regeneration, under specific circumstances: following premature felling as a result of a pest or disease pest outbreak on the site; PAWS restoration following clear-fell. The objective is to support an increase in the capacity for sustainable management through this process.

Woodland creation grant
This grant provides funding for woodland creation to expand and join up existing woodland.

Woodland planning grant
Support for the drafting of a UKFS-compliant woodland management plan to promote appropriate management interventions and resilience planning.

Further information and advice

Forestry Commission **Likely impacts of climate change on England's woodlands**.

Forestry Commission 2011 **UK Forestry Standard Guidelines on Forests and Climate Change**.

Forestry Commission England 2010 **Managing Ancient and Native Woodland in England** Practice Guide.

JNCC (2008) UK BAP habitat description **Lowland Mixed Deciduous Woodland**.

Key evidence documents

UK National Ecosystem Assessment – **Chapter 8 Woodland**

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Broadmeadow MSJ, Morecroft MD, Morison JIL . (2009a). Observed impacts of climate changes UK forests to date. In: Read, D.J., Freer-Smith, P.H., Morison, J.I.L., Hanley, N., West, C.C. and Snowdon, P. (eds). *Combating climate change – a role for UK forests. An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change*. Chapter 4. Pg 50-66.The Stationery Office, Edinburgh.

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Forestry Commission 2012 **Woodland Area, Planting and Restocking**

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Beech and Yew – Wealden Edge Hangers SSSI, Hampshire

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, and 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 can grow on both acidic and calcareous soils, although its association with yew 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 form 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 Cephalanthara 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 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 common 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	Implications
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 (epiphytes, fungi, invertebrates). ■ Changed ground flora composition.
Wetter winters	Spring waterlogging	■ Reduced nutrient uptake and reduced vigour of beech (Carey 2013, Geßler et al. 2007). ■ Increased susceptibility to summer drought.
Warmer summers	Longer growing season	■ 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 in beech in parts of Britain. ■ Increased 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 mature 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 existing 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 (including grey squirrel) , pollutants, over-grazing and development pressures. 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.
- 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 more secure water supply (eg 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 such as ash and oak within the canopy of 'beech woods'.
- Where the climate is projected to becomes suitable, accept beech as component of semi-natural woodland in areas beyond its current native range.

Mature beech in Buckholt Wood, Gloucestershire

Relevant Environmental Stewardship options

Maintenance of woodland (HC07)

Restoration of woodland (HC08)

The aim of these options is to maintain or restore farm woodlands to benefit wildlife and protect and strengthen the local landscape character. It is only appropriate where the woodlands are part of the farmed landscape.

Priority is given to woodlands with ancient semi-natural characteristics and sites with remnants of ancient semi-natural woodland such as planted ancient woodland sites (PAWS) and grazed woodland.

Relevant English woodland grant options

The majority of woodland grants available under the English Woodland Grant Scheme closed to new applicants before April 2014. The grants outlined below, as set out in England's next Rural Development Programme document, will be available when the new scheme opens in 2015 and, in some cases during the 2014 transition period. Up to date information is available from the Forestry Commission's **Grants and Regulations** web-pages.

Woodland Infrastructure Grant (replacing the **Woodfuel Woodland Improvement Grant**). This grant supports the sustainable production of wood by improving access to woodland for management and harvesting purposes. The grant will cover a proportion of the cost of work, and will not take account of the timber income that results.

Woodland Improvement Grants
Grants to fund the improvement in the quality of woodlands to achieve specific objectives, through either capital investments or five-year revenue payments. Current priorities are: bringing priority habitats into target condition; supporting priority species (particularly birds and red squirrels); PAWS restoration through gradual conversion; and improving climate resilience through conversion to continuous cover approaches to management.

Woodland Regeneration Grant
Woodland Regeneration Grant (WRG) contributes to the costs of making changes to the composition of woodland within the normal cycle of felling and regeneration, under specific circumstances: following premature felling as a result of a pest or disease pest outbreak on the site; PAWS restoration following clear-fell. The objective is to support an increase in the capacity for sustainable management through this process.

Woodland creation grant
This grant provides funding for woodland creation to expand and join up existing woodland.

Woodland planning grant
Support for the drafting of a UKFS-compliant woodland management plan to promote appropriate management interventions and resilience planning.

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**.

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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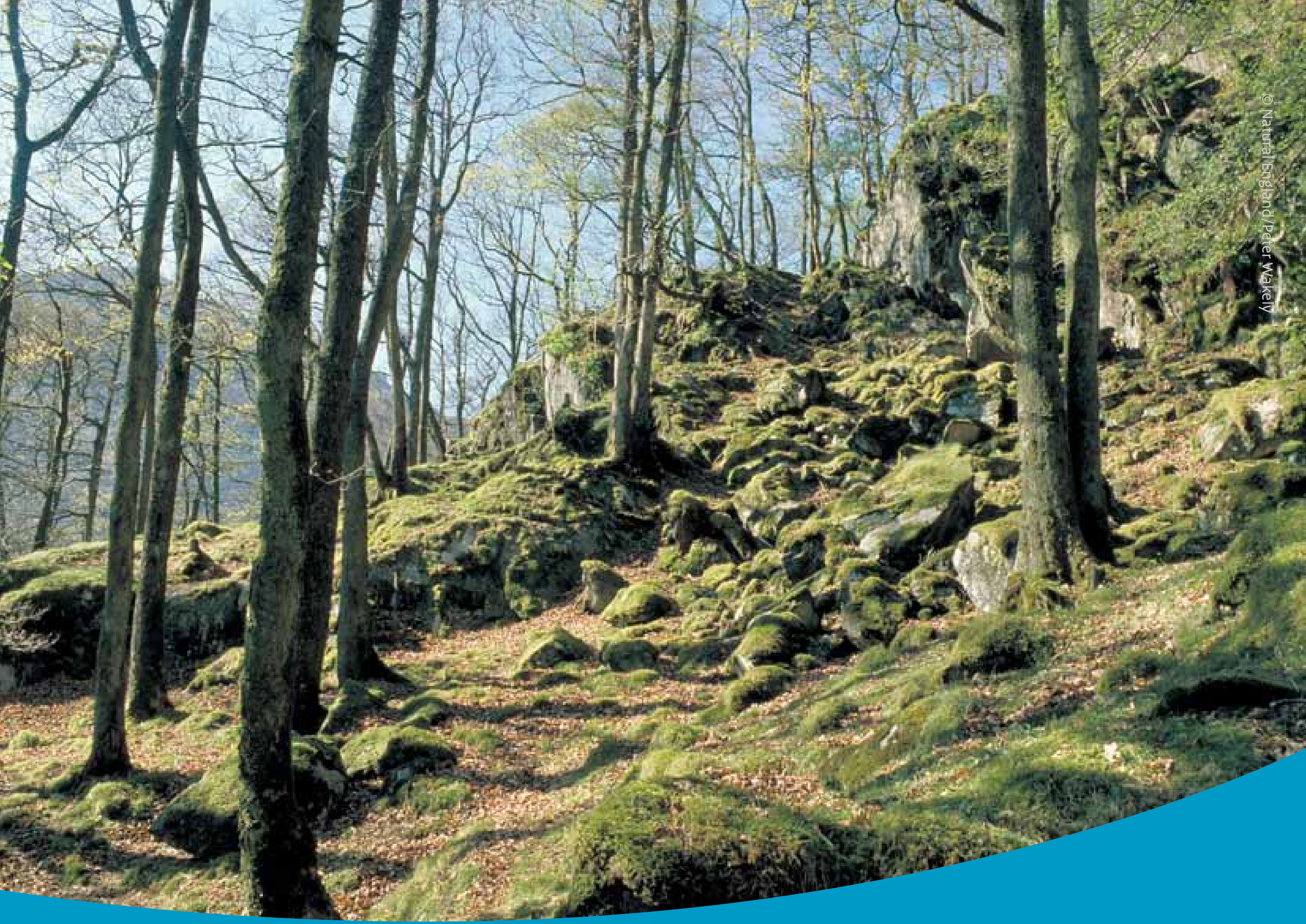

Upland Oak. Johnny Wood SSSI, Borrowdale

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, but locally pedunculate) and birch in the canopy, with varying amounts of holly, rowan and hazel 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 plants 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, 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 30-40,000ha 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 and grey squirrel could lead to reduced regeneration and loss of ground flora.
Drier summers	Reduced soil moisture and drought Increased risk of wildfire	■ 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). ■ 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 windblow 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, (including grey squirrel) 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 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.

Oak and ferns. Wistman's Wood, Dartmoor.

Relevant Environmental Stewardship options

Maintenance of woodland (HC07)

Restoration of woodland (HC08)

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Woodland creation grant
This grant provides funding for woodland creation to expand and join up existing woodland.

Woodland planning grant
Support for the drafting of a UKFS-compliant woodland management plan to promote appropriate management interventions and resilience planning.

Further information and advice

Forestry Commission, The management of semi-natural woodland 5. Upland Oakwoods.

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UK Biodiversity Action Plan (2008) Priority Habitat Descriptions. BRIG (ed. Ant Maddock).

Upland mixed ash woodland. Crathes Castle, Aberdeenshire

4. Upland mixed ash woodland

Climate change vulnerability: **Low**

Introduction

Ash *Fraxinus excelsior* is a very 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 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, sycamore, rowan, bird cherry, and birch may also be present. 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.

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 bio-diverse 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 bright displays of 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 harbour 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 damage from deer browsing, grey squirrels or pheasants, pollution from agricultural spray drift, soil compaction and erosion, and the spread of invasive species such as Himalayan balsam.
- 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 grow.
- 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 and/or fauna.
- Aim to buffer smaller sites by extending the woodland edge and 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 (eg 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, diseases and the increased risk of major new disturbance events such as wildfires.

Mixed ash/alder woodland. Forest of Ae, Scotland

Relevant Environmental Stewardship options

Maintenance of woodland (HC07)

Restoration of woodland (HC08)

The aim of these options is to maintain or restore farm woodlands to benefit wildlife and protect and strengthen the local landscape character. It is only appropriate where the woodlands are part of the farmed landscape.

Priority is given to woodlands with ancient semi-natural characteristics and sites with remnants of ancient semi-natural woodland such as planted ancient woodland sites (PAWS) and grazed woodland.

Relevant English woodland grant options

The majority of woodland grants available under the English Woodland Grant Scheme closed to new applicants before April 2014. The grants outlined below, as set out in England's next Rural Development Programme document, will be available when the new scheme opens in 2015 and, in some cases during the 2014 transition period. Up to date information is available from the Forestry Commission's **Grants and Regulations** web-pages.

Woodland Infrastructure Grant (replacing the **Woodfuel Woodland Improvement Grant**).
This grant supports the sustainable production of wood by improving access to woodland for management and harvesting purposes. The grant will cover a proportion of the cost of work, and will not take account of the timber income that results.

Woodland Improvement Grants
Grants to fund the improvement in the quality of woodlands to achieve specific objectives, through either capital investments or five-year revenue payments. Current priorities are: bringing priority habitats into target condition; supporting priority species (particularly birds and red squirrels); PAWS restoration through gradual conversion; improving climate resilience through conversion to continuous cover approaches to management.

Woodland Regeneration Grant
Woodland Regeneration Grant (WRG) contributes to the costs of making changes to the composition of woodland within the normal cycle of felling and regeneration, under specific circumstances: following premature felling as a result of a pest or disease pest outbreak on the site; PAWS restoration following clear-fell. The objective is to support an increase in the capacity for sustainable management through this process.

Woodland creation grant
This grant provides funding for woodland creation to expand and join up existing woodland.

Woodland planning grant
Support for the drafting of a UKFS-compliant woodland management plan to promote appropriate management interventions and resilience planning.

Further information and advice

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Wet woodand. Ickburgh, Norfolk

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 Biodiversity Action Plan priority 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 understorey composition.
Warmer winters	Fewer frost events	■ Increased survival of mammal pests such as deer and grey squirrel, resulting in more damage to thin barked trees and reduced regeneration. ■ 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.

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

- Reduce the impacts of other pressures, such as pests and diseases, (including grey squirrel) pollutants, over-grazing and development pressures. 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 within the canopy.

- 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 (eg 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.

Mature wet birch, alder riparian woodland, Crathes Castle, Aberdeenshire

Relevant Environmental Stewardship options

Maintenance of woodland (HC07)

Restoration of woodland (HC08)

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Woodland creation grant
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Woodland planning grant
Support for the drafting of a UKFS-compliant woodland management plan to promote appropriate management interventions and resilience planning.

Further information and advice

Forestry Commission (1994) Practice note **The Management of Semi-natural Woodlands 8. Wet Woodlands**.

Sussex Otters and Rivers Project **How to create and restore wet woodlands**.

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Pollarded oak. Hatfield Forest SSSI, Essex

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 waterlogging. 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	Implications
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 and 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. Also, management of younger trees to encourage the development of dead and decaying wood to fill the gap between veterans and younger trees will 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 (ie 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.
- 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 (eg cedar, redwood) 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.

Veteran oak, Calke Abbey, Derbyshire

Relevant Environmental Stewardship options

Maintenance of wood pasture and parkland (HC12)

Restoration of wood pasture and parkland (HC13)

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.

Creation of wood pasture (HC14)

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.

Woodland Trust **Ancient Tree guide no. 5 Trees and Climate Change**.

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Bramley apple orchard, Cambridgeshire

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 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 – 200 plus years, so there is a risk of existing trees either dying or being replaced because they are not commercially viable any more, 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, but are generally 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.

Grazing or cutting the understorey is integral to orchard management, as it is in wood-pasture and parkland. 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 17,000ha.

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 in 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. ■ 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[18]. 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 inequalis. ■ 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 and woodpeckers may be lost, while other species, including Wryneck and Hoopoe, may become established. ■ Current winter species, including redwing and fieldfare, may no longer visit. Other species may start wintering here with warmer winters, eg blackcap 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).

18 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 understory.
- 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 fireblight.
- 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 and retaining dead wood.
- 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

Relevant Environmental Stewardship options

Maintenance of high value traditional orchards (HC18)

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. Some planting of traditional varieties of orchard trees species may be required if there are gaps in the orchard. Ongoing management will require suitable livestock grazing and the protection and maintenance of the trees. Capital payments may be made for restorative pruning of old trees.

Maintenance of traditional orchards in production (HC19)

This is aimed at orchards currently managed on a commercial basis where fruit production and tree health are important considerations. Appropriate fertilisers, pesticides and management techniques are allowed. If more restorative pruning or new planting is required the restoration option should be considered.

Restoration of traditional orchards (HC20)

This option applies to existing traditional orchards, managed extensively for wildlife and historic landscape benefits, that are under-stocked or in need of restoration. The option aims to restore degraded orchards by re-planting traditional varieties of orchard trees to restore tree numbers to an appropriate level.

Creation of traditional orchards (HC21)

This option is highly targeted to re-creating orchards on sites that are known to have previously been orchard. The option may also be used in appropriate areas to help support specific threatened species such as the rare noble chafer beetle. Planting of traditional varieties of orchard tree species will usually be required in the first two years of the option.

Further information and advice

Natural England has produced a number of publications about orchards, including the following 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 blossom

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 that 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 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 adaptations 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 species, particularly those that are adapted to 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, 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 only very slowly and the microclimate of 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.
- Maintain 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 then 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

Relevant Environmental Stewardship options

Hedgerow management is largely covered by the Entry Level scheme of Environmental Stewardship:

Hedgerow management for landscape (on both sides of a hedge) (EB1)

Hedgerow management for landscape (on one side of a hedge) (EB2)

Hedgerow management for landscape and wildlife (EB3)

These options encourage rotational management of hedges with a restriction on the frequency of cutting. Cutting is also restricted to periods that do not overlap with the bird breeding season. Each option is also available in combination with ***ditch management (EB08-10)***.

An additional option that encourages the restoration of hedges, ***Hedgerow restoration (EB14)***, is also available under ELS.

Under the Higher Level scheme, there are two options available for hedges of high environmental value:

Management of hedgerows of very high environmental value (both sides) (HB11)

Management of hedgerows of very high environmental value (one side) (HB12)

These options encourage management hedgerows that support target species of farmland birds, insects or mammals, such as the tree sparrow, brown hairstreak and dormouse. It also aims to maintain hedgerows that make a significant contribution to the local landscape character and/or are historically important boundaries. They should only be used where tailored, outcome-specific management is to be implemented above that required by ELS hedgerow management. Management will reflect the distinctive historic and landscape character of the local area, and should be sympathetic towards the protection and enhancement of the identified target features.

In addition to annual payments for management, one–off payments are available under the Higher Level scheme for hedgerow restoration and planting.

Hedgerow planting - new hedges (PH)

This option involves the establishment of new hedgerows with locally occurring, native species, to offer significant landscape and wildlife benefits.

Hedgerow restoration, includes laying, coppicing and gapping up (HR)

This option covers laying, coppicing and gapping-up to restore neglected hedges.

Several supplements are also available for additional work required to support hedgerow planting or restoration ***HF Hedgerow supplement - removal of old fence lines***; ***HSC Hedgerow supplement - substantial pre- work*** and ***HSL Hedgerow supplement - top binding and/or 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 **Hedgerow Regulations**. 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

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 intensity 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. 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 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	■ 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).
	Increase in pests and diseases	■ 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 threaten 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, eg 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.

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 for species. Field margins have an important role in increasing the permeability of an otherwise hostile environment thereby aiding 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, increase 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

Relevant Environmental Stewardship options

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

2-6m buffer strips on cultivated land (EE01-03)

These low intensity grassland buffer strips can be established through natural regeneration or 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.

Floristically enhanced grass margin (HE10)

This option creates a floristically diverse 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.

Wild bird seed mixture (HF02)

This option is a sown mix of cereals and legumes and will provide important food resources for farmland birds, especially in winter and early spring, 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.

Nectar flower mixture (HF04)

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 (eg red clover, alsike clover, bird's-foot-trefoil, sainfoin, musk mallow, common knapweed). It provides valuable benefits to wildlife at a landscape scale and is ideally suited to larger blocks and small fields.

Beetle banks (EF07)

Beetle banks are tussocky grass ridges, generally about 2 m 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.

Unfertilised cereal headlands (HF09)

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.

Uncropped cultivated margins for rare plants (HF11)

An arable field margin is cultivated annually in either spring or autumn to a depth of about 15 cm. 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**.

Key evidence documents

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The River Avon at Ibsley, Hampshire

10. Rivers and streams

Climate Change Sensitivity : **High**

Introduction

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 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 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 (eg salmonids and many benthic invertebrate species) and of species adapted to low nutrient and well-oxygenated conditions (eg 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 killer shrimp *Dikerogammarus villosus*, have already made their way to the UK.

Habitat Description

There is very wide variation in this broad habitat type, ranging from intermittent and perennial headwater streams, to cool, energetic upland brooks and warm, sluggish lowland rivers. 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.

Connectivity is extremely important in river systems. Rivers change along their length as they flow from source to sea, and these changes lead to broad longitudinal patterns of biological zonation. As climate changes, these zonation patterns will migrate upstream and downstream according to shifts in optimal environmental conditions for individual species. The only natural limits to these migrations, 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 are generally likely to be more 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.

The UK BAP recognises a number of different river types as being of importance for biodiversity, including chalk rivers, active shingle rivers, and headwaters, but 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 UKBAP definition of priority habitat to separate out different river types. A broad priority habitat definition is used, 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 range of pollutants, from both effluents and diffuse sources. In particular, 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 widely 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.

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. Overuse 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 habitat integrity 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 groundwaters on which they depend can lead to ecological damage. Balancing the needs of the river ecosystem with society's needs for water could 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 (eg fish, molluscs, crustaceans) will find it difficult to migrate with climate space. 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 (eg 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 and 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 (eg 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 affect the scope for restoring river ecosystems in ways that will improve resilience to climate change.

Adaptation responses

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 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.
- 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 agricultural land management.

In the river corridor and floodplain

Maintaining and restoring natural river processes are likely to be the most effective adaptation measures for climate change within river corridors and floodplains (Kernan et al. 2012). Natural river processes provide the most characteristic and self-sustaining mosaic of river biotopes (Mainstone and Holmes 2010), 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 (eg 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 river 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 (eg 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 Environment Agency has published guidance[18] on this.
- 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 where appropriate.
- Where possible, restore natural biological connectivity within the river network and between the river channel and floodplain, by removing artificial barriers. 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 (eg fishless headwaters) and should not be removed.
- 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 as the key climate change adaptation measure for river ecosystems. Development should be focussed on existing impoundments that cannot be removed, and on in-line turbines that do not remove water from the river channel.

18 Environment Agency (2011) Keeping Rivers Cool - Getting ready for climate change by creating riparian shade

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

Relevant Environmental Stewardship options

Most of the actions outlined above cannot be supported by Environmental Stewardship. The most relevant Environmental Stewardship options relate to resource protection prescriptions – 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. 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.

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Watendlath Tarn, Cumbria

11. Standing open water

Climate Change Sensitivity: **High**

Introduction

Warmer temperatures will threaten the persistence of some species on the southern edge of their range such as arctic char, 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 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.

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 of standing waters. 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 load 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. Increased temperatures will lead to reduced dissolved oxygen concentration. Deoxygenation of the microzone at the sediment surface will lead to a release of phosphate from the sediment, increasing the nutrient load to the lake from internal sources.

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.

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. Species reliant on cold and/or oxygenated water will have their habitat reduced by increased temperatures and reduced oxygen concentrations. More frequent storms and wetter winters will increase run-off and sedimentation, which can cover substrates and macrophytes and alter the habitat within some standing waters.

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, when connecting watercourses may dry out. 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.

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

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 Cheshire Plain marl pits, 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 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. Some water bodies in this category may naturally have been mesotrophic, but have become eutrophic through human influences. Mesotrophic lakes lie in the middle of the trophic range and as a consequence have a high botanical diversity, but are sensitive to nutrient enrichment. Mesotrophic lakes are relatively infrequent in the UK and are largely confined to the margins of upland areas in the north and west. 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.

The total area of still inland water is estimated at 675 km2 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 and erosion of marginal features.
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 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. ■ Loss of submerged macrophyte species, and their possible replacement 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 such as arctic charr Salvelinus alpinus and northward spread of some southern species (Morecroft and Speakman, 2013). ■ 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	■ Increased exposure of the littoral zone, leading to increased erosion lower down the littoral zone, greater water level fluctuations, and stress for some aquatic plant species. Some species like shoreweed Littorella uniflora are tolerant of immersion and only reproduce sexually when immersed. 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 rivers, ditch systems and other freshwater 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 load 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 (eg abstraction, water diversion/transfer) and controlling non-native species.

Establishing ecological networks and ensuring hydrological connectivity is maintained between connected sites is important to allow species to migrate between sites in response to climate change. However, many standing waters are naturally isolated and 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 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

- Maintain or restore lake marginal habitat and emergent structure to provide areas protected from wave action.
- Maintain or restore hydrological connectivity between sites where it has traditionally existed.
- 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 pollutant loads from effluents to minimise impacts on the natural nutrient status and to minimise concentrations of toxins.
- 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.

Aqualate Mere NNR, Staffordshire

Relevant Environmental Stewardship options

Most of the actions outlined above cannot be supported by Environmental Stewardship. The most relevant Environmental Stewardship options relate to resource protection prescriptions – 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. 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.

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Catfield Fen, Ant Broads and Marshes NNR, Norfolk

12. Lowland fens

Climate Change Sensitivity: **High**

Introduction

Lowland fen is 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 and may in many cases be compounded by increasing demand for water leading to increased abstraction.

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 (eg 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, it is essential that the ecohydrological function of the individual wetland (ie 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, from acid through to highly alkaline, 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.

In areas where base-rich water occurs in more nutrient rich conditions, tall species-rich fen may develop, eg 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 reedmace.

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 in among 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, base-rich low nutrient fens are limited to areas with calcium-rich groundwater, and basin fens with floating acidic rafts tend to occur in hummocky, often post-glacial, landscapes. The estimated area of lowland fen in England is 25,785 ha[19].

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 abstraction for agriculture and domestic use leading to 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.
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. ■ Increased nutrient input, leading to benefits for those species able to utilise enhanced levels, and the potential loss of nutrient-poor 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 salt marsh habitat.

19 JNCC Extent & Distribution of UK Lowland Wetland 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 provides.

Removing or reducing pressures on wetlands, including groundwater abstraction, drainage and nutrient enrichment will continue to be important. 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 appropriate, for example on sites that have been created and sustained wholly by human intervention, but in most 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 particularly circumstances.

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

- Determine and characterise 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 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 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 ecohydrological 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.
- Where circumstances dictate consider actions that enable water tables to be artificially maintained during the spring and summer including the use of artificial structures.
- 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.
- Where currently present, aim to maintain areas that are permanently wet/inundated habitats with little fluctuation of water levels.
- 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 grazing to facilitate the transition into a species rich lowland meadow type habitat, or allow and encourage scrub and tree development to move the site towards wet woodland. However, care will be needed to separate the impacts of climate change from avoidable pressures. 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 off-setting that loss through habitat creation and restoration inland.
- Locations for the restoration or creation of fen habitats should be identified at the planning stage of flood management schemes within river floodplains.

Boardwalks Local Nature Reserve, Peterborough.

© Natural England/Peter Wakely

Relevant Environmental Stewardship options

Maintenance/Restoration of fen (HQ06/07)

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.

Creation of fen (HQ08)

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.

Wetland cutting (HQ11)

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.

Wetland grazing (HQ12)

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.

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.

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

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.

Key evidence documents

Keller, J.K., White, J.R., Bridgham S.D. & Pa S To R, J. (2004) Climate change effects on carbon and nitrogen mineralization in peatlands through changes in soil quality. *Global Change Biology* 10, 1053–1064.

Graves, A.R. and Morris, J. 2013. **Restoration of Fenland Peatland under Climate Change** Report to the Adaptation Sub-Committee of the Committee on Climate Change. Cranfield University, Bedford.

Yare Broads and Marshes SSSI

13. Reedbeds

Climate Change Sensitivity: **Medium**

Introduction

Reedbed is 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 reedbed and other lowland fen habitat.

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*, crane *Grus grus*, Cetti`s warbler *Cettia cetti*, Savi`s warbler *Locustella luscinioides* and bearded tit *Panurus biarmicus*, and 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 red 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 5000 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	Implications
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. Water management and vegetation management are necessary to maintain conditions for the persistence of reed- dominated vegetation. 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.

- 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 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

Relevant Environmental Stewardship options

Maintenance of reedbeds (HQ03Restoration of reedbeds (HQ04)

These options are 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.

Creation of reedbeds (HQ05)

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.

Wetland cutting (HQ11)

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**, and (2010) **Fens and Mires update**.

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**.

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.

Norfolk Wildlife Trust. The **Hilgay wetland creation project** 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

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 defined as 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[20] mires (springs, flushes, valley fens) and topogenous[21] 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).

The habitat tends to be small in area and located within other upland habitats. Although small, their contribution to 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, 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 (eg *Molinia*, *Phragmites*), and/or a carpet of bryophytes eg *Sphagnum* spp., *Cratoneuron* spp., and occasionally wetland herbs (eg meadowsweet *Filipendula ulmaria*). Vegetation is generally short (less than 1m and often less than 30cm) but can sometimes be taller in swamps.

The habitat frequently supports a rich flora of vascular plants with many rare species eg scorched alpine-sedge *Carex atrofusca*, bristle sedge *C. microglochin*, sheathed sedge *C. vaginata*, mountain scurvygrass *Cochlearia micacea*, alpine rush *Juncus alpinoarticulatus*, two-flowered rush *J. biglumis*, chestnut rush *J. castaneus*, three-flowered rush *J. triglumis*, false sedge *Kobresia simpliciuscula*, Iceland-purslane *Koenigia islandica*, Yellow Marsh Saxifrage *Saxifraga hirculus* and Scottish asphodel *Tofieldia pusilla*. It is also exceptionally important for bryophytes with notable species including Lindberg's Bog-moss, cleft Bog-moss, slender green feather-moss *Hamatocaulis vernicosus* , Scottish Beard-moss *Bryoerythrophyllum caledonicum* and Silky swan-neck moss *Campylopus setifolius*. It also may also be important as nesting habitat for waders, such as curlew, snipe and redshank and can support a varied 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

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

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. Other areas support more acidic valley mire systems, such as Dartmoor and Bodmin Moor. In general, this habitat is poorly surveyed and the full extent of its interest and value is not well known. The extent of this habitat is difficult to assess because the habitat has not been comprehensively surveyed in many areas and tends to occur in small, sometimes numerous stands.

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 in upland springs. ■ Extreme rainfall events could lead to increased peat slippage.
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.

Maintaining the quality, quantity and temporal variation of water is likely to be the main adaptation challenge. In the short term, this may take the form of managing and impeding drainage networks, but over the longer term will require planning at the catchment level to restore the natural capacity of catchments to hold water and maintain flows under wet and dry conditions.

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.

- Ensure that negative off-site impacts are minimised, through the appropriate management of surrounding habitats to avoid run-off, erosion and drainage.
- Ensure that the hydrological regime of the site is protected and enhanced, for example through drain and gully blocking and re-profiling water courses.
- 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.

Bog pimpernel Anagallis tenella and tormentil Potentilla erecta. Base rich flush on the Long Mynd, Shropshire.

Relevant Environmental Stewardship options

HL9 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.

HL10 Restoration of moorland

This option is aimed at restoring moorland where not all habitat is in good condition, to benefit upland wildlife, retain historic features and strengthen the landscape character. This option can also promote good soil management, which will reduce diffuse pollution. In addition it may, in the right situation, provide an area of flood storage and some benefits to flood risk management.

Both options include prescriptions, programmes and plans that include stocking regimes, burning (or not burning), cutting and scrub and bracken management, which enable management to be tailored to habitats including upland flushes, fens and swamps.

Further information and advice

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

Biodiversity Planning Toolkit **Upland flushes, fens and swamps**.

Key evidence documents

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Purple Moor-grass meadow at Chippenham Fen NNR, Cambridgeshire

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 both from intensification through agricultural improvement or loss due to cultivation and/or 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 dependant 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 transition to drier habitats.

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/or 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/or invasion by woody species. 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 *Eurodryas aurinia*, small pearl-bordered fritillary *Boloria selene*, narrow-bordered bee hawkmoth *Hermaris 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 such as Lapwing 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, 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 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	■ Summer water-logging could result in vegetation dieback and an increased incidence of bare ground, leading to colonisation by ruderal species. ■ 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 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 2013). ■ 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, 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.

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. Removing or reducing pressures on wetlands, including groundwater abstraction, drainage and nutrient enrichment, will be of increasing importance. As well as dealing with licensed activities such as abstraction, this may 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.

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 the size of existing patches 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.

There are various existing initiatives to improve the availability of water and water quality, including the Water Framework Directive 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, 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 return 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, eg 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.
- 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 grazing to facilitate a transition towards species rich lowland meadow type habitat.
- Locations for the restoration or creation of fen habitats should be identified at the planning stage of flood management schemes within river floodplains.
- Restore natural hydrological processes where this would enhance resilience of habitats.

Snipe in boggy pasture

Relevant Environmental Stewardship options

Maintenance of species-rich, semi-natural grassland (HK06)

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

Restoration of species-rich, semi-natural grassland (HK07)

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.

Wetland grazing (HQ12) - £200/Ha

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) Protecting and enhancing wetlands: Ecohydrological Guidelines for Lowland Wetland Plant Communities and (2010) Fens and Mires update.

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

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Blanket bog on Fleetwith Pike, Cumbria

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 (eg 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. A possible scenario is that bryophyte species currently found on blanket bogs that have a tolerance or preference for drier conditions will come to dominate the vegetation.

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 and 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), atmospheric deposition and visitor pressure, 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 and management (burning, grazing and drainage) 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	■ 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. ■ Increased fire risk, especially where degraded blanket bog is dominated by heather or grasses such as purple moor-grass Molinia. ■ Peat will become more susceptible to damage under wildfire or managed burns. ■ Improved accessibility for visitors could lead to increased erosion and risk of wildfires. ■ Areas of peat on moorland edges will become suitable for 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.
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 problems of over grazing. ■ 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, and 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 range 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 introducing 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.
- Encourage structural diversity within areas of blanket bog by, for example, adjusting grazing levels and using a range of species, breeds, ages and sizes of animal.
- In regions where climate change may reduce the area of blanket bog, such as the Peak District and the Yorkshire 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.
- Evidence of any relationship between climate change and increased visitor numbers should be investigated through monitoring, and visitor management plans developed to reduce the risk of erosion and wildfire on sensitive sites.

Hare's-tail cottongrass, an important plant of peat bogs.

Relevant Environmental Stewardship options

HL9 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 landscape character. The option can also promote good soil management, which will reduce diffuse pollution.

HL10 Restoration of moorland

This option is aimed at restoring moorland where not all habitat is in good condition, to benefit upland wildlife, retain historic features and strengthen landscape character. This option can also promote good soil management, which will reduce diffuse pollution.

Both options include prescriptions, programmes and plans that include stocking regimes, burning (or not burning), cutting and scrub and bracken management, which enable management to be tailored to habitats including blanket bog.

Further information and advice

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

Cumbria Biodiversity partnership information brochure **Blanket Bog**.

Climate change and upland peat loss: implications for policy – An information note produced by Bristol and Bangor universities.

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.

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

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Rodwell, J S (Ed) 1991 *British Plant Communities Vol. 2: Mires and heaths*. CUP, Cambridge
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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 JR, Drewitt AL & Measures GH. (2010). Managing for species: Integrating the needs of England's priority species into habitat management. Part 1 Report. Natural England Research Reports, Number 024.

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Dorset heaths

17. 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. Coastal and dune heathlands may be lost if sea levels rise significantly. Warmer temperatures could cause grass species to become more dominant as a result of increased nutrient availability, 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 which has already expanded its range. The fragmented nature of many heathland sites will increase their vulnerability to climate change.

Heathland is also sensitive to potential indirect impacts of climate change such as increased recreational pressure, and extreme weather events such as flooding will impact on the ability to undertake restoration and maintenance work in the winter.

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 (eg 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.
Hotter summers	Increased evapotranspiration	■ Drying of sites may cause a change in balance of species, particularly on wet heathland areas. ■ Increased risk of wildfire.
	Potential for increased visitor numbers	■ 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 (eg 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 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). ■ 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).
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 addition 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).

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 benefits in terms of shading and reducing 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.

Relevant Environmental Stewardship options

Maintenance of lowland heathland (HO01)

This option is designed to encourage the appropriate management of existing lowland heathland sites in good condition. Such sites require active management input to retain their ecological value. Sensitive management, using a combination of grazing, cutting and removal, or burning will be required.

Restoration of lowland heathland (HO02)

This option is aimed at restoration of lowland heathland that is not currently in good/favourable condition, including on sites whose management has been neglected. Such sites are likely to have become degraded by scrub, bracken, gorse, invasive grasses or secondary woodland encroachment, and in some cases overgrazing and too frequent burning, and may or may not currently be under active management.

Restoration of forestry areas to lowland heathland (HO03)

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.

Creation of lowland heathland from arable or improved grassland (HO04)

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.

Creation of lowland heathland on worked mineral sites (HO05)

This option is intended to encourage the creation of lowland heathland on previously worked mineral sites. No natural seed bank is likely to be present. 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 worked mineral sites will help to re-create and strengthen the vegetation mosaics characteristic of lowland landscapes.

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Heather and gorse. Dunkery and Horner Woods NNR

18. 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 created 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 600-750 m) and above the upper edge of enclosed agricultural land (generally at around 250-400 m). 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 *Calluna 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 0.4m 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 species, including red grouse *Lagopus lagopus*, black grouse *Tetrao tetrix*, merlin *Falco columbarius* and hen harrier *Circus cyaneus*. 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 risk of wildfire	■ An increase in unmanaged access could lead to more erosion on access routes, an increased risk of wildfires (Albertson et al 2010), and increased disturbance of ground nesting birds (eg 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. ■ Improved accessibility for visitors could potentially lead to increased erosion and risk of wildfire (Albertson et al. 2010). ■ 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 (eg 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

Relevant Environmental Stewardship options

Maintenance of moorland (HL09)

Restoration of moorland (HL10)

These options aim to maintain or restore areas of moorland habitats to ensure they are in good condition to benefit upland wildlife.

Creation of upland heathland (HL11)

This option aims to (re-)create dwarf shrub communities (upland heath) in upland moorland areas where dwarf shrubs are rare or absent and their seed banks are depleted. It will be targeted at areas adjacent or close to existing dwarf-shrub heath. The option will help to (re-)create and strengthen the diverse vegetation mosaics characteristic of upland landscapes.

The management objectives and prescriptions will vary widely according to the nature of the site and the success of initial treatments.

Management of heather, gorse and grass by burning, cutting or swiping (HL12)

This supplement supports the establishment of an appropriate programme of rotational vegetation management. This may involve either an increase or decrease in management activity.

Moorland re-wetting (HL13)

This supplement supports the re-wetting of moorland to maintain wetland habitats and their associated wildlife and conserve the vegetation mosaics and landscape features characteristic of upland landscapes.

Seasonal livestock exclusion (HL15)

This supplement is aimed specifically at sites where major moorland restoration is necessary and achievable, or for further improving moorland in good condition. It can only be applied where additional environmental benefit will be achieved by removing more stock than is required by the standard moorland option. Examples of such benefits include: increasing the rate of heather regeneration; or allowing rare species to flower (eg spring gentian) or regenerate (eg juniper).

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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Risby Warren SSSI, Lincolnshire

19. 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 UK.

Potential climate change impacts

Cause	Consequence	Implications
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	■ Drier conditions will favour stress-tolerant (eg 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[19] 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).
	Wildfire	■ 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.

19 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.

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.
- 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 climatic 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

Relevant Environmental Stewardship options

Maintenance of species-rich, semi-natural grassland (HK06)

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

Restoration of species-rich, semi-natural grassland (HK07)

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

Creation of species-rich, semi natural grassland (HK08)

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

Supplementary options

Grazing supplement for cattle (HR1)

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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Plantlife Information about grassland habitats and their management.

Relevant case study examples

Creation of lowland dry acid grassland at Minsmere, Suffolk : RSPB
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 is well established but is 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.

20. 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-colonization 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. ■ 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 – eg 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).

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 and 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.
- 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.

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Adonis blue Lysandra bellargus

Relevant Environmental Stewardship options

Maintenance of species-rich, semi-natural grassland (HK06)

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

Restoration of species-rich, semi-natural grassland (HK07)

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.

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

Climate Change Adaptation and Biodiversity in the Isle of Wight (2009)
This report is a good example of a local climate change risk assessment and adaptation plan. It presents the key findings and recommendations from an extensive literature review, that have particular relevance to the landscape, ecosystems, habitats and species of the Isle of Wight, including lowland calcareous grassland, and uses the EBS principles to identify appropriate adaptation responses.

Wiltshire Chalk Country
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

21. 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.

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 (eg 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.

Cause	Consequence	Potential impacts
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 2013).
More extreme events	Flooding	■ 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 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.

Snake's head fritillary. North Meadow, Cricklade NNR

Relevant Environmental Stewardship options

Maintenance of species-rich, semi-natural grassland (HK06)

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

Restoration of species-rich, semi-natural grassland (HK07)

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.

Creation of species-rich, semi natural grassland (HK08)

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

Supplementary options

Haymaking (HK18)

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.

Raised water levels (HK19)

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.

Grazing supplement for cattle (HR1)

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**.

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

Plantlife. Guide to grassland habitats and their management.

Relevant case study examples

Species-Rich Grassland Restoration on the River Nene, Northamptonshire, UK
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.

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Grazing marshes and dyke, Halvergate Marshes SSSI, Norfolk

22. 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 tetanus*, and curlew *Numenius arquata*. Internationally important populations of wintering wildfowl also occur, including Bewick's swans *Cygnus 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 *Odonomyia 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 off 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	Implications
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 (eg 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 dependant 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 man-made habitat created by drainage and flood defence, 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 (ie 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.

Cattle grazing, Cabin Hill NNR, Merseyside

Relevant Environmental Stewardship options

Maintenance of traditional water meadows (HD10)

Restoration of traditional water meadows (HD11)

These options maintain or restore the traditional management required on water meadows, including catch meadows, where irrigation is achieved through a system of inlet and outlet channels.

Restoration/Maintenance of wet grassland for breeding waders, wintering waders and wildfowl (HK09-12)

These options aim to continue or restore the management of seasonally wet grassland to support overwintering and breeding waders and wildfowl. Existing water management regime will be continued or modified to provide conditions that will continue to attract lowland breeding waders.

The following options can be used in combination with the HK options where relevant:

Management of ditches of very high environmental value (HB14)

This option is aimed at the management of ditches that support target species of plants, birds, mammals and insects.

Raised water level supplement (HK19)

This supplement is aimed predominantly at raising water levels in ditches, and thus adjacent land, at key periods of the year.

Inundation grassland supplement (HQ13)

This option is designed to provide additional areas of flooding by inundation with floodwater from adjacent watercourses.

Further information and advice

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

Rodwell JS, Morgan V, Jefferson RG & 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.

Essex Biodiversity Project **Lower Raypits and Lion Creek Higher Level Stewardship Restoration Project**

Key evidence documents

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Drake CM, Stewart NF, Palmer MA & Kindemba VL (2010) **The ecological status of ditch systems: an investigation into the current status of the aquatic invertebrate and plant communities of grazing marsh ditch systems in England and Wales**. Buglife – The Invertebrate Conservation Trust.

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Upland hay meadow, Wensleydale

23. Upland hay meadow

Climate Change Sensitivity: **Medium**

Introduction

Many species that make up Upland Hay meadow are expected to be relatively resilient to projected climate change (Berry et al 2005). However, key species such as wood cranes bill *Geranium sylvaticum* and melancholy thistle *Cirsium heterophyllum* which belong to boreal-montane floristic elements are likely to decline 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[22] 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 1000 ha in northern England.

Potential climate change impacts

Typical species of these grasslands include those that are adapted to cooler climates and may become out competed by species adapted to higher temperatures as the climate becomes warmer. Initially this will come from other species within the present grassland community, but over time more southerly specie may well 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.

22 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.

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. This might include, for example, varying the timing of the hay cut or the date of shut-up or closure for growing hay, or changing the timing, duration and extent of aftermath grazing.
- Adjust cutting and grazing dates to align with changes to the flowering date.
- 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

Relevant Environmental Stewardship options

Maintenance of species-rich, semi-natural grassland (HK06)

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

Restoration of species-rich, semi-natural grassland (HK07)

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.

Creation of species-rich, semi natural grassland (HK08)

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

Supplementary options

Haymaking (HK18)

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.

Further information and advice

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

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

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

Plantlife Information about grassland habitats and their management.

Relevant case study

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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Pinches, C.E., Gowing, D.J.G., Stevens, C.J., Fagan, K. & Brotherton, P.N.M. 2013.

Natural England review of upland evidence - Upland Hay Meadows: what management regimes maintain the diversity of meadow flora and populations of breeding birds? Natural England Evidence Review, Number 005.

Rodwell, J. S. ed. 1992. *British Plant Communities. Volume 3, Grasslands and Montane Communities*. Cambridge, UK: Cambridge University Press.

UK Biodiversity Action Plan; Priority Habitat Descriptions. BRIG (ed. Ant Maddock) 2008.

Hayeswater, Cumbria

24. 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, eg 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, potentially, a 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.

Curlew *Numenius arquata*

Relevant Environmental Stewardship options

Maintenance of species-rich, semi-natural grassland (HK06)

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

Restoration of species-rich, semi-natural grassland (HK07)

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 introduction of seeds and 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.

Further information and advice

The Grassland Trust.

Plantlife Guide to grassland habitats.

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.

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Scafell from Coniston Old Man. Lake District, Cumbria

25. 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 (eg Britton *et al*).

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 lie 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 (Upland Management Handbook).

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 (eg woolly fringe-moss *Racomitrium lanuginosum*) and/or lichens (eg *Cladonia* species); and siliceous alpine and boreal grasslands with stiff sedge *Carex bigelowii* and moss heaths. Rarer vegetation types include snow-bed communities with dwarf willow *Salix herbacea* and various bryophytes and lichens, and sub-arctic willow scrub (as described in McLeod and others, 2005).

Montane habitats are extensive in the Scottish Highlands, but are highly localised in England and Wales and tend to be relatively small and fragmented, and support 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 2300 ha in England.

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 risk of wildfire (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 under 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).
Global impacts	Potential changes to the economics of upland grazing and shooting systems	■ Some alpine heaths have been shown require grazing to survive and could be lost if grazing is removed (Miller, G.R. et al).

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 (eg alpine saxifrage *Saxifraga nivalis*), but for others (eg 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 and 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 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 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

Relevant Environmental Stewardship options

HL9 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.

HL10 Restoration of moorland

This option is aimed at restoring moorland where not all habitats are in good condition, to benefit upland wildlife, retain historic features and strengthen the landscape character. This option can also promote good soil management, which will reduce diffuse pollution. In addition it may, in the right situation, provide an area of flood storage and some benefits to flood risk management.

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
Report of 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

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Sand Dunes at Holkham NNR, Norfolk

26. 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 eg Druridge Bay, Northumberland; spit dunes, which form as sandy promontories at the mouths of estuaries eg 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 eg Sefton Coast, Merseyside. The total area of sand dunes in England is approximately11,897 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 stabilization 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 hence 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 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.
- Ensure hydrological conditions are fully conserved to offset potential reductions in rainfall, where possible. 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 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 addressed specifically.

The Natterjack toad is found in a handful of places and breeds in warm shallow ponds in sand dunes and sandy heaths

Relevant Environmental Stewardship options

Maintenance of sand dunes (HP01)

Restoration of sand dunes (HP02)

These options, which rely on seasonal grazing, are only suitable on fixed dune grasslands and heaths that can be maintained either by grazing with stock or by mowing, and on vegetated swards that can be grazed by stock.

Creation of coastal vegetated shingle and sand dunes on arable land (HP03)

Through detailed planning and management, this option supports the creation/expansion of sand dune and vegetated shingle systems on arable land where there are suitable underlying sediments. This option will help to re-create and strengthen the distinctive local character of coastal landscapes.

Further information and advice

The Sand Dune and Shingle Network
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 Margin Habitats**, in MCCIP Annual 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 (2005) **Shifting Shores - Living with a changing coastline**
To gain a better understanding of how coastal change will affect National Trust properties, the Trust commissioned Halcrow Group Ltd to study how erosion and flooding might affect its coastal sites over the next 100 years.

National Trust (2008) **Shifting shores in the South West**

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Saltmarsh at Lymington, Hampshire

27. 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 migrate inland given the accommodation space (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 driftline, 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.

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 area 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 wall 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 increases the wave energy reaching sea walls, with impacts on maintenance costs.
Increased annual average temperatures	Changes in the relative climate space available to saltmarsh species	■ Changes to community composition, with an increase in graminoid[20] species over forbs[21] (Gedan & Bertness 2009). ■ Potential loss of suitable climate space for some key saltmarsh species eg Sea purslane Atriplex portulacoides, common saltmarsh grass Puccinellia maritima and ■ Annual seablite 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.

20 Grasses, sedges and rushes
21 Herbaceous species

Cause	Consequence	Potential impacts
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).

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 sufficient space is available for saltmarsh to develop naturally and migrate inland, and identifying sites for managed realignment to compensate for habitat lost. 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 and 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 (eg 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.

The Alkborough Flats re-alignment scheme in North Lincolnshire will reduce flood risk and create new habitats.

Relevant Environmental Stewardship options

Maintenance of coastal saltmarsh (HP05)

Restoration of coastal saltmarsh (HP06)

These options aim to maintain and restore coastal saltmarsh. The management will depend on the particular conditions on a site. It could include light grazing, restrictions on grazing, controlling damaging activities associated with public access, or dealing with accumulations of normal coastal litter.

Further information and advice

Environment Agency (2007) Saltmarsh management manual.

Environment Agency Shoreline Management Plans.

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Relevant case studies

Abbotts Hall Farm – Essex Wildlife Trust
The Abbotts Hall Farm project on the Blackwater Estuary is a special managed realignment scheme, and has demonstrated 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, which improves the standard of flood protection and creates important new intertidal wildlife habitat and recreational opportunities.

Alkborough Flats Tidal Defence Scheme, South Humber Estuary.

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Part 3

Ecosystem Services and climate change

Introduction

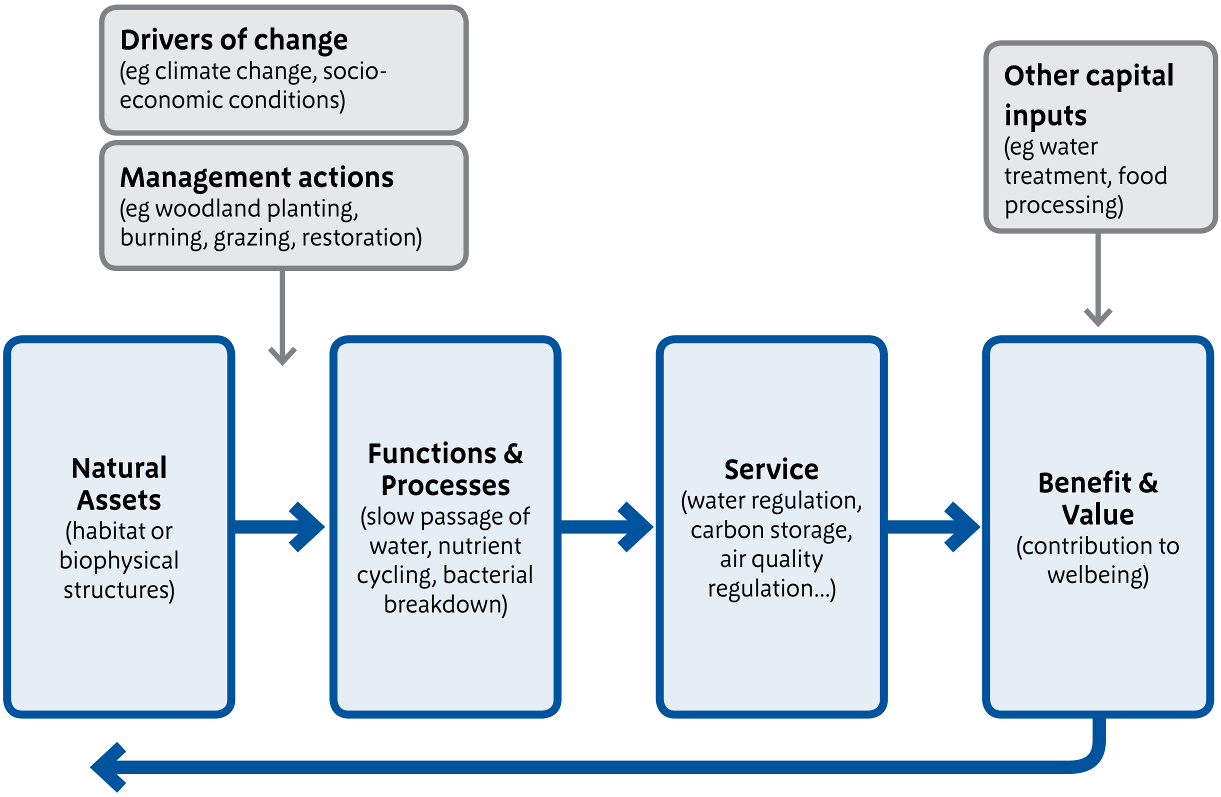
The natural environment, its landscapes, habitats and biodiversity provide ecosystem services to people - benefits to society that are often under-noticed and undervalued. Four broad categories of ecosystem services are now widely recognised: supporting, provisioning, regulating, and cultural. These 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, provide 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 grasslandLowland 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 eg 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 (eg 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 (eg 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 (eg drought) may be countered by responses to another (eg elevated carbon dioxide) or management responses (eg 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 intend to address these impacts in future editions of this manual, which will be developed to include recreation and access, the historic environment, and landscape character.

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 (eg soil erosion, flood damage). Trees, standing vegetation and peat (eg wind throw of trees). **Cultural** Wild species diversity (eg loss of coastal and freshwater habitat, loss of species sensitive to high nutrient levels). Environmental settings (eg changes in landscapes with erosion, deposition and flood damage). Recreation (eg footpath erosion and closures). **Regulating** Climate (eg erosion and dissoluton of stored carbon in soils). Hazard (eg landslides, increased flood risk). Water quality (eg 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 (eg agricultural land loss due to erosion). Livestock/aquaculture (eg risk to livestock of increased coastal flooding). Trees, standing vegetation and peat (eg affected by salination of soils). Water supply (eg saline intrusion of groundwater). **Cultural** Wild species diversity (eg loss of coastal and freshwater habitat). Environmental settings and recreation (eg loss of beaches and dunes). Historic environment (eg erosion of coastal archaeological sites). **Regulating** Climate (eg changes in stored carbon in soils),. Hazard (eg increased flooding, landslips). Water quality (eg saline intrusion). Soil quality (eg 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 (eg changes in crop selection). Livestock/aquaculture, fish (eg affected by low flows) Trees (eg changes in forestry productivity). Water supply (eg loss to evapotranspiration). Cultural services Wild species diversity (eg montane species no longer within climatic limits). Environmental settings, recreation (eg algal blooms affecting water-based activities). Historic environment (eg affected by changes in plant growth on archaeological sites). **Regulating** Climate (eg loss of stored carbon with wild fires). Hazard (eg changes in soil erosion with changes in soil formation). Disease and pests (eg increase in prevalence of pests and diseases, such as Lyme disease with increased tick survival in warmer winters). Pollination (eg bumblebee declines with climatic niche shifts (Williams et al 2007) changes in timing of flowering and the emergence of pollinators). Water quality (eg deterioration with increased concentrations of nutrients). Soil quality (eg with changes in soil formation). Air quality (eg 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.	**Provisioning** Crops/livestock (eg reduced crop yield). Aquaculture, fish (egwith low flows and deterioration in water quality). Trees, standing vegetation, peat, (eg reduced timber yield). Water supply (with low flows). Cultural Wild species diversity (eg affecting species intolerant of drought). Environmental settings (eg draw down on reservoirs). Recreation (eg water-based). **Regulating** Climate (eg loss of soil carbon). Water quality (eg increase in pollutant concentration). Soil quality (eg desiccation). Air quality (eg decreased removal of air pollutants by plants, as stomata are closed with low soil moisture levels).
		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.	

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. **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.	**Provisioning** Crops (eg changes in crop productivity). Livestock (eg loss of grazing land due to water-logging). Aquaculture, fish (e.g affected by increased sediment loads in rivers). Water supply (eg increases in water availability in winter). Cultural Wild species diversity (eg affecting species intolerant of water logging). Environmental settings (eg flood damage). **Regulating** Climate (eg with changes in soil organic matter and stored carbon). Hazard (eg increase in frequency of landslips). Disease and pests (eg increased risk of combined sewer overflow pollution). Water quality (eg with increased soil erosion). Soil quality (eg with increased surface run-off and leaching).
Increased CO_2	Increased CO_2 fertilisation	The water cycle Changes in evapo-transpiration as a result of changes in plant growth and vegetation community composition. 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.	Provisioning Crops, livestock, aquaculture, fish, trees, standing vegetation, peat, (eg affected by changes in plant growth). Water supply (eg 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 (eg reduced uptake of ozone through plant stomata due to increased atmospheric CO_2).

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:
Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term
Ecosystem processes are characterized 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 recognize 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 utilize 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 and advice.

Further information

UK National Ecosystem Assessment
UK Climate Change Risk Assessment Evidence Report 2012

Key evidence documents

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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, ie 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.

S**pecial 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.

UKCP09 – The UK Climate Projections (UKCP09) 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
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. © Mike Page

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