Living With Environmental Change

Biodiversity
Climate Change Impacts

Report Card 2015

This publication summarises the impacts that climate change is having on land-based and freshwater species, habitats and ecosystems in the UK. It also present the best available scientific evidence of the mechanisms causing change and what may happen in future.

This is one of a series of Report Cards published by the Living With Environmental Change Network. This summary is underpinned by a series of technical papers written by experts in the field, with the project overseen by a working group of senior scientists. Both the summary and technical papers have been peer-reviewed. In total, over 40 scientists from more than 20 different research and conservation organisations have contributed to this publication.

This Report Card updates and extends the previous version produced in 2013. The key messages remain similar, but the rapid pace of research has improved understanding in several areas. There is also new material on freshwater ecology and soil organisms.

The Report Card covers the following topics:

- Changes in UK climate
- Emerging patterns
- Plant communities and habitats
- Species
- Ecological processes and interactions

Headline messages

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

Our climate is already changing. In some cases, changes can be at least partly linked to the influence that people are having on the climate system. In other cases, we may be able to detect a trend but are not yet able to say what is causing it. It is particularly difficult to attribute the cause of changes at the scale of the UK, where the climate is naturally very variable and there are other influences on the climate system. It is even harder to look at changes in the frequency and severity of extreme events. By their nature they are rare occurrences and so there are limited observational data to study.

This section summarises the changes we have already seen and describes how we expect the climate to change in future.

What has happened

- **Average temperatures** have increased by nearly 1°C since the 1980s. All of the top ten warmest years for the UK have occurred since 1990. This includes 2014, which was the warmest year on record in the UK.
- **Average annual rainfall** has varied from year to year. In the past few decades there has been some increase in annual average rainfall over the UK, particularly over Scotland. However, the longer term trend is less clear from records of rainfall over England and Wales since 1766.
- **Seasonal rainfall** is highly variable but over the last century or so winter rainfall appears to have increased. Over the same period, summer rainfall has decreased but the trend is less clear and recently there have been some wet summers. Over the past 50 years, heavy rainfall events have made an increasing contribution to winter rainfall in the UK.
- **Sea level** around the UK rose by about 1-2mm/year during the 20th century, with the rate of rise varying from decade to decade and increasing to over 3mm/year in the past decade. Peak sea levels during extreme weather events appear to be rising at a similar rate.
- **Severe wind events** have become more frequent in the past few decades, although it is not clear whether this is part of a long-term trend.

Sources: **Met Office National Climate Information Centre (NCIC) UK climate statistics 1910-2014. http://www.metoffice.gov.uk/climate**

England and Wales Precipitation series 1766 – 2014. http://www01/obs_dev/od4/series/ewp.html

Hanna E. *et al.* (2008) J. Climate, 21, 6739–6766.

Donat M.G. *et al.* (2011) Natural Hazards and Earth Sciences, 11: 1351-1370

UK mean sea level estimates based on Woodworth *et al.* (2009) International Journal of Climatology 29: 777–789; data courtesy of the National Oceanography Centre (Liverpool)

What could happen

- **Temperature:** All UK regions are expected to warm – more so in summer than in winter. Changes in average summer temperatures are expected to be greatest in parts of Southern England and least in the Scottish Islands.
- **Rainfall:** Models indicate little change in overall average rainfall but significant seasonal and regional variation. Projections have indicated a risk of lower summer rainfall in future decades, particularly in Southern England, and indicate a trend towards higher winter rainfall, particularly in the west of Britain. Whilst summer rainfall may decline on average, rainstorms may become heavier when they do occur.
- **Sea level:** This will continue to rise around the UK, probably at a faster rate than observed in the last century. This will lead to higher peak sea levels during extreme weather events.
- **Humidity:** Relative humidity may decrease by up to 5-10% during summer, with the greatest reductions in Southern England and smaller reductions further north. In winter, changes could amount to a few percent or less, across the UK.
- **Solar radiation:** This may increase on average, with the greatest increase expected in Southern England.
- **Fog:** Although uncertainty surrounds changes in the occurrence of fog, the annual number of 'fog days' is expected to fall by 20-50% with the largest decreases in Northern Britain and North Wales. During winter, there may be an increase of 5-20% in the number of fog days across Southern Britain and the Midlands.
- **Wind:** Changes to atmospheric circulation may shift storm tracks (i.e. severe winds associated with low-pressure systems) north or south, although changes in wind speeds are uncertain.

Note: estimates of changes in fog and wind generated by climate models are particularly uncertain.

Sources: **Murphy J. *et al.* 2009. UKCP09 Science report. Met Office Hadley Centre, Exeter**

Boorman P. *et al.* 2010. UK Climate Projections 2009: Future change in fog frequency. Met Office Hadley Centre, Exeter

Sexton D.M.H. & Murphy J. 2010. UKCP09: Probabilistic projections of wind speed. Defra, London.

Haigh I. *et al.* 2010. Shelf Research, 30(9):1042-1055.;

Kendon E.J. *et al.* 2014. Nature Climate Change, 4:570-576.

How are biodiversity and ecosystems in the UK responding to climate change?

The key findings presented in this Report Card are summarised under 22 separate topics. These are grouped into four categories: Emerging patterns; Plant communities and Habitats; Species; and Processes and Interactions.

Symbols included in the text indicate:

- the level of scientific confidence attached to individual statements
- changes in the scientific consensus for these confidence levels that have occurred since publication of the 2013 version of this Report Card
- those areas where significant new evidence now exists to underpin our findings.

Confidence ratings

High Confidence	H
Medium Confidence	M
Low Confidence	L
Confidence has increased	↑
Confidence has Decreased	↓
New material included in this edition of the Report Card	✱

The strongest evidence for the impact of climate change, particularly rising temperatures can be found in changes in individual species life-cycle timing and altered species distribution and migration patterns. These changes have occurred across a wide range of species and habitats. The composition of many ecological communities is also changing. In the majority of cases, new evidence has strengthened our confidence in these emerging patterns.

Changes in timing of life cycle events (phenology)

Sparks & Crick

Moss

Morrison & Robinson

Neaves *et al.*

What is happening

Spring life-cycle events, such as leafing, flowering and egg laying, have advanced in most species that have been recorded; the average advance has been nearly two weeks over the last few decades. ■ H

Evidence exists that the timing of some autumn events is changing, such as a delay in leaf fall and the fruiting of fungi. ■M↑

Most changes in phenology are best explained as an effect of rising temperatures. ■H

Phenology may be affected by a range of additional factors in some species, such as a requirement for low temperatures over winter, increasing day length, changes in rainfall, nutrients and water supply, and increases in carbon dioxide. These give rise to differences between species. ■H

The majority of species that have adjusted their timings to warmer climates are likely to have done so mainly through individual developmental and behavioural changes, rather than through evolutionary change. ■M

Evolutionary changes in phenological characteristics as a response to climate have been demonstrated in some species (e.g. freshwater zooplankton) that have short generation times (i.e. species where the average time between two consecutive generations is short). ■M✱

Changes in species' phenology have not been uniform. For example, the advance in springtime events has been smaller in species that are higher up the food chain. ■H✱

Geographical variation in phenological change is widespread even within the same species, because of variations in local climatic conditions and, in some cases, evolutionary adaptation of local populations. ■H

What could happen

Many spring life-cycle events are likely to advance further in the future. ■H✱

Autumn life-cycle events are likely to occur progressively later. ■L✱

The combined effect of earlier spring and later autumn life-cycle events may allow an increase in the number of generations of some species (e.g. aphids and butterflies) and in plant productivity, so long as water or other resources are not limiting. ■M✱

Species that do not adjust their phenology in response to climate change are more likely to experience declines in population, as this can affect the way they synchronise with other species as well as their productivity. There is also recent evidence that they are more likely to show shifts in distribution. ■M✱

Skylark nest and chicks © Natural England/P.N. Watts

Hawthorn flower © Natural England/ Allan Drewitt

What is happening

There is some evidence that urban heat islands are having an impact, with phenology being more advanced in urban areas than in the surrounding countryside. ■M✱

What could happen

Species likely to be most at risk from changing phenology are those that use environmental cues not directly related to climate (e.g. day length), have a narrow ecological niche, rely on few species at a lower level in the food chain, have low mobility or have low reproduction rates. ■M✱

Range shifts

Pateman & Hodgson

Gillingham

Pearce-Higgins

Ellis

Neaves *et al.*

Many animal species, especially those with more southerly distributions, are colonising new areas to the north of their historical range, consistent with recorded increases in temperature; good data are available for a range of groups including birds, butterflies and dragonflies. ■H

There is some evidence that there has been a shift to higher altitudes by some species. Average range margins have shifted 25m uphill over the last 20-25 years. ■M

Rates of change in species' range margins differ; most are not moving as fast as the change in temperatures we have seen in recent decades. ■H↑

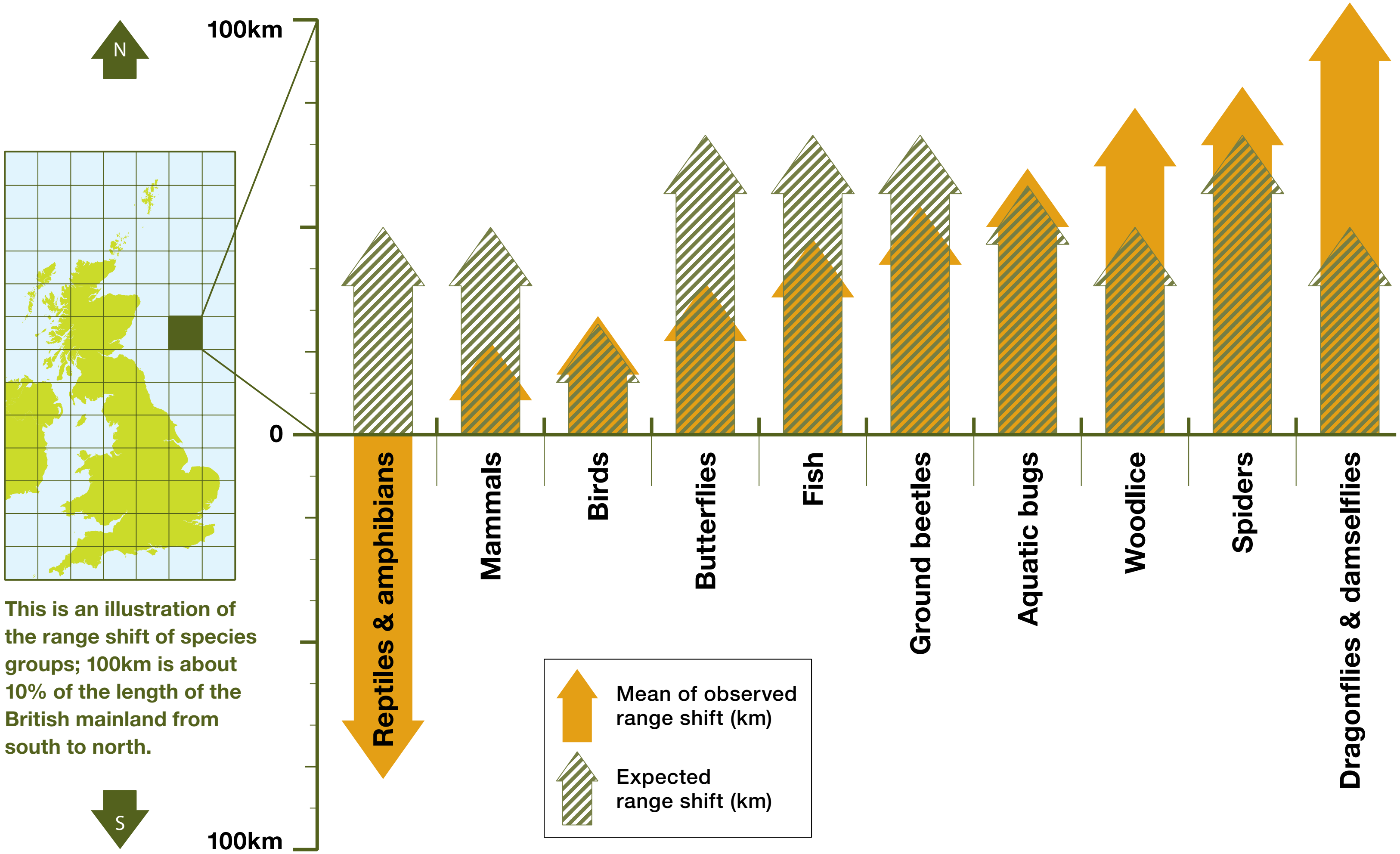
Species are likely to continue to shift their distribution northwards and to high altitudes in response to increasing temperatures. ■H

Interactions between species, including competition, are likely to influence the patterns of species' range shifts in areas that are newly suitable from a climatic perspective; so too will land use and management. ■H

Species that are unable to shift distribution to keep pace with climate change may experience reduction in their range extent and local extinction. Vulnerable species include those on isolated mountain tops or in fragmented habitats as well as those with slow rates of dispersal and low reproductive rates. ■M

Banded Demoiselle Damselfly © Natural England/Allan Drewitt

Adonis blue butterfly © Natural England/Peter Wakely



This is an illustration of the range shift of species groups; 100km is about 10% of the length of the British mainland from south to north.

This illustrates data on the mean observed shifts in northern range margin for a range of species studied within species groups (Hickling R. et al 2006. Global Change Biology, 12, 450-455) across 20-25 year timescales spanning 1960-2000 alongside data on the expected range shift of these species groups across the same timescale responding to current levels of climate change (Chen I-C et al 2011. Science, 333, 1024-1026). This is to show whether species groups are keeping up with their expected range shifts using this data and to highlight that it is not just changes in climate that species have to deal with, other issues affect species ability to keep pace with what is expected. For more detail please see the Range Shift technical paper (Pateman & Hodgson).

	What is happening	What could happen
Range shifts continued Pateman & Hodgson Gillingham Pearce-Higgins Ellis Neaves *et al.*	Range limits are affected by local microclimate as well as broad trends. Expansion can occur first in warm micro-sites at cool range margins and extinction can be prevented or delayed by cool micro-sites at warm range margins. ■M✱ There are fewer examples of plant species distributions shifting compared to animals. Plants have tended to respond to changes in climatic conditions by altering the timing of life-cycle events and growth. ■M↑ There is some evidence that northern and montane animal species, including birds and some butterflies (e.g. the mountain ringlet), are retreating at southern or low-altitude range margins. ■L✱ Genetic adaptation is facilitating range expansion by increasing dispersal ability or altering species interactions in some cases. ■L↓ There is evidence both for species preferentially colonising protected conservation sites when spreading north and for them persisting longer in protected areas at their southern range margins. ■M✱	Because there are more species with northern range margins than southern ones in the UK, more species may increase than decrease in this country. Those species expanding in the UK may be declining in their ranges across Central or Southern Europe. ■M Expanding species will tend to be those with a relatively warm, southerly distribution (e.g. the Dartford warbler and the Adonis blue butterfly). Species for which areas of suitable climate are likely to contract are those typically found in cold areas, including the common scoter and arctic-montane bryophytes and lichens. ■M In protected areas, representation of habitats and species typical of northern latitudes will decrease, while representation of those more typical of southern latitudes will increase. ■H
Non-native species and colonisation Hulme Mossman, Franco & Dolman De Vries & Bardgett	Since 1800, patterns of introduction of non-native species have mainly been consistent with the growth of international trade and long-distance transport. However, climate change and evolution have favoured the spread of some species once these have become established. ■H Warming is likely to have facilitated a number of recent natural colonisations of the UK by species from continental Europe (e.g. damselflies, such as the southern emerald). ■M↑	The threats posed by non-native invasive species, pests and diseases will increase in future as the climate becomes suitable for larger numbers of species. This includes the possibility that some established non-native species will increase their distribution and abundance. The nature of this process is complicated by other factors such as land-use change and interactions between species. ■M It is very difficult to predict which species will become invasive. Non-native species that may potentially establish themselves in the near future include the North American corn western rootworm (with the UK currently on the edge of its climatic range), the tiger mosquito, escaped horticultural plants such as the paradise tree and aquatic plants such as parrot's feather and water lettuce. ■L Colonisation by new plant species may lead to insects and other invertebrates using different species; this has been observed in gardens with cultivated plants. ■L

Migration

Morrison & Robinson

Evans & Pearce-Higgins

Pearce-Higgins

Sparks & Crick

Moss

What is happening

In recent years, there has been a tendency for many summer migrant bird species to arrive earlier. The advance has been greater for those with shorter migration distances than for intercontinental migrants and greater for early arriving species than for later arriving species. ■H

Evidence for changes in autumn migration departure dates is mixed. ■L❋

Migratory journey length has been decreasing for many short-distance migrants travelling between the UK and continental Europe or within the UK. This reflects milder winters and has both reduced cold weather deaths and increased breeding success. ■H❋

A number of wintering wildfowl and wader species have declined significantly in their abundance in the UK, particularly in west coast estuaries, as they migrate shorter distances in the non-breeding season and many have shifted north-eastwards to new feeding grounds. ■H❋

Common Whitethroat © Natural England/Allan Drewitt

What could happen

Numbers of many waders, such as dunlin, will continue to decline in the UK as birds winter elsewhere. ■M

Some waterfowl (e.g. the velvet scoter and long-tailed ducks) are likely to decline as a result of the reduced quality of their Arctic breeding environments caused by warming. ■L

Eurasian Oystercatcher © Natural England/Allan Drewitt

Because of the dependence of many migratory bird species on wetland habitats, they may be disproportionately affected by projected trends of reduced summer rainfall and lower water tables that affect prey availability. ■M

Trans-Saharan migrants may face an increasingly severe barrier to their northwards spring migration as a result of desertification in the Sahel region in Northern Africa. ■M↑

For some bird species, advances in the timing of breeding may mean more nesting opportunities or a longer window to carry out their annual moult; for others, it might lead to earlier departure dates from breeding grounds. ■L❋

Emerging patterns

Red Knot: Melting permafrost reduces breeding habitat area.

Barnacle Goose: Milder winters lead to shorter migration journeys

Pied Flycatcher: Earlier arrival at breeding grounds

Kittiwake: Shifts in prey distribution caused by temperature change

Honey Buzzard: migration route influenced by changing storm tracks over the mediterranean sea

Whitethroat: changes in stopoverwuality due to increased drought frequency

Garden Warbler: Migration patterns impacted by climate interations with deforestation

This presents examples of climate change impacts on migratory birds. The map shows projected surface temperature changes for the late 21st century (2090-2099) for the A1B SRES scenario (AR4:SPM.6), with darker colours indicating greater change. Arrows indicate broad directions of migration towards breeding areas. © IPCC, Paul Doherty, John Dunn, Edmund Fellowes, John Harding, Amy Lewis and Rob Robinson.

Migration continued

Morrison & Robinson

Evans & Pearce-Higgins

Pearce-Higgins

Sparks & Crick

Moss

What is happening

Populations of long-distance trans-Saharan migrants breeding in the UK (e.g. the sedge warbler and whitethroat) are affected by survival rates in their African wintering grounds; these in turn are affected by changes in African climate and particularly by reductions in rainfall which have contributed to desertification. ■ **H**

New migratory insects are arriving in the UK from Continental Europe and some existing summer migrants are becoming permanent residents; for example, the red admiral butterfly is increasingly overwintering in the UK. ■ **H**

What could happen

Substantial changes in the strength, direction and timings of prevailing winds during migration could have a major impact on some species, particularly birds of prey. ■ **L**

Changes in spring phenology are likely to affect the synchronisation of migration with food availability en-route and at breeding grounds, although the effects will vary between species. ■ **M**

Red Admiral Butterfly © Natural England/ Allan Drewitt

Wigeon are one of the wildfowl which occur in their thousands on the flood plain meadows of the Lower Derwent Valley National Nature Reserve © Natural England/Peter Roworth

Plant communities are important for the species that compose them, the habitats they provide for other species and as a central element of the landscape. Most of the common species that provide the structure of habitats in the UK have wide biogeographic ranges, which gives them a degree of resilience to climate change but those at their range margins are likely to be particularly affected by climate change. All communities are likely to experience some degree of change as competition, pollination and other interactions between species change. Climate change will also interact with the wide range of other factors influencing plant communities, including changes in land use, land management and air pollution. Some of the UK's most iconic landscapes and habitats are particularly vulnerable to climate change, including montane, wetlands and coastal habitats.

Montane

Carey

Ellis

What is happening

There is evidence that rising temperatures have contributed to changes in the composition of vegetation in the Scottish Highlands, including a decrease in arctic-montane species. ■M

Repeat surveys of snow-bed vegetation in Scotland have demonstrated a shift towards a less distinctive community, with an increase in species such as highland rush and a decrease in specialist snow-bed liverworts. ■H❋

Upland mountain view, Fleetwith, Lake District, Cumbria © Natural England/Paul Glendell

What could happen

Mountain-top plant communities are composed of species adapted to low temperatures and are likely to decline in response to rising temperatures, as a result of increasing colonisation and competition from upland species typical of lower altitudes. ■H

Snow-bed communities are vulnerable to reduced snow cover during warmer winters, which and are likely to become increasing uncommon. ■H

Late lying snow-bed on the East Drumochter Hills © Lorne Gill/SNH

What is happening

What could happen

Heathlands

Carey

Heather and gorse on moorland, North Exmoor, Somerset © Natural England/Paul Glendell

Lowland heath in South East England is potentially vulnerable to climate change, with reduced rainfall leading to changes in species composition. ■ M

Higher temperatures may allow bracken to invade areas of upland heath, particularly where bare peat or areas of degenerative heather are present. ■ M ✱

Upland heathland may start to become more like lowland heathland in terms of plant community composition, especially in South West England. ■ M ✱

The composition and structure of upland heathlands are vulnerable to wildfire; fire risk may well increase with warmer conditions and any seasonal decrease in rainfall. ■ M

Semi-natural grasslands

Carey

Sparks & Crick

Increasing temperatures have promoted earlier spring greening of grasslands and a longer growing season. ■ H

Following dry summers, there is often an increase in plants that colonise bare ground (e.g. the prickly ox-tongue or field thistle in agricultural grasslands or recently established semi-natural grasslands). ■ H

Long-established, low-nutrient grassland communities show relatively little change through warm, dry summers. ■ M ✱

Many grasslands are likely to remain similar in character with a rise in temperature of a few degrees. However, some changes in species composition would be expected, especially where species are on the edge of their climatic tolerances (e.g. in upland hay meadow communities). ■ L ✱

Some grasslands are likely to be very sensitive to changes in rainfall, particularly those that are associated with waterlogged conditions for part or all of the year. An increase in summer droughts could lead to a decline in distinctive wet grassland communities, including water meadows and rush pastures. This may be offset by changes in winter precipitation and in catchment characteristics. ■ L ✱

Chalk downland flora, Hampshire © Natural England/Chris Gomersall

What is happening

Wetlands: bogs, fens, marshes and swamps

Carey

Pearce-Higgins

Ellis

The occurrence and nature of wetland habitats are determined by their water supply. Climatic factors including rainfall, snow, fog and evapotranspiration are an important element of this, together with ground and surface water which are also affected by catchment characteristics (e.g. soil type). ■H✱

Ditch and reeds on Pevensey Levels, East Sussex © Natural England/Peter Wakely

What could happen

A reduction in rainfall in summer months would adversely affect many wetland habitats. Lowland fens are particularly likely to be under increasing threat in South East England. ■M

Modelling suggests a reduction in the area which would support actively growing blanket bog, particularly under high emissions climate scenarios. Drier eastern and southern areas would tend to be more vulnerable than those to the west and north, although healthy blanket bogs have a high degree of resilience. ■M↓

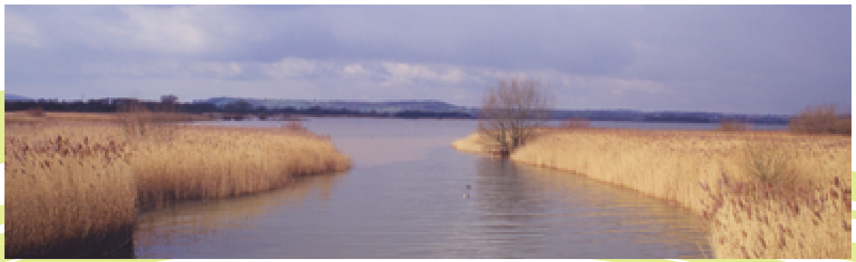
Many blanket bogs have been degraded as a result of drainage, over-grazing, burning and eutrophication (i.e. over-enrichment with nutrients) and are more vulnerable to drying and erosion. Restoration (e.g. through blocking of drainage channels and re-vegetating bare peat) would be expected to reduce blanket bog vulnerability to climate change and is expected to enable its persistence in many areas, provided that threshold levels of moisture are met. ■M✱

Freshwater: rivers, ponds and lakes

Moss

To date, human-induced impacts through drainage, engineering, damming and use of fertilisers have had a greater impact than climate change on freshwater ecology. ■H✱

Warmer temperatures have increased the symptoms of eutrophication (excess nutrients leading to algal growth) in both plankton and lake-shore plant communities; an example is Loch Leven in Scotland. ■M✱



Indirect climate changes that lead to greater nitrogen deposition and that influence the severity of eutrophication will be more important than direct temperature effects on freshwater systems unless the temperature changes are large; in that case there will be major changes in fish communities, reflecting their heat tolerance. ■H✱

Through increased flooding and increased drought, climate change may have positive effects in maintaining pond biodiversity, but permanent ponds may become temporary. ■M✱

Chew Valley Lake, Avon © Natural England/Peter Wakely

Woodland

Carey

Sparks & Crick

Ellis

Evans & Pearce-Higgins

What is happening

Tree death following drought has been recorded at long-term monitoring sites; beech, birch and sycamore are more sensitive to drought than other species. This can lead to major changes in the composition and structure of woodland. There is also evidence of reduced growth rates in a range of tree species during dry summers. ■H❋

Jonny Wood, Borrowdale with bryophyte covered stones © Natural England/Peter Wakely

What could happen

Lowland beech woodland and wet woodland would be adversely affected by more frequent or more extreme summer drought in the drier parts of the UK. ■M

Pests and diseases (both those that are currently present in the UK and those that may be introduced from elsewhere) represent a major threat to woodland. These threats may be increased by interactions with the direct effects of climate change on tree function. ■M

Different phenological responses (e.g. between canopy and ground flora and between different elements of food webs) could alter woodland composition; so could increases in herbivore numbers as a result of warmer winters. ■L

As an indirect climatic effect, changes in woodland structure could have an important impact on communities of epiphytes that grow on the trees including many mosses. ■L

Wild garlic in woodland © Natural England/Julian Dowse

Coastal and intertidal

Mossman *et al.*

What is happening

Rising sea levels combined with the impacts of hard sea defences have been associated with the loss of coastal habitats, with intertidal habitats such as salt marsh experiencing the greatest losses. ■H

Increased air and sea surface temperatures have resulted in changes in the range sizes and distribution of a number of coastal animals. Warmer-water species are shifting northwards (e.g. the molluscs *Osilinus lineatus* and *Gibbula umbilicalis*) and warm-water kelp has become more abundant beyond its southern margin. ■H

Where southern and northern species with similar niches occur, there has been a relative increase in abundance of the southern species. *Coelopa pilipes*, a coastal strandline fly with a southern distribution, has expanded its UK range northwards and become more abundant, whereas the northerly species *C. frigida* has declined. ■H

Rates of change observed in marine species have been greater than those observed in land-based and freshwater species. Warmer sea temperatures have advanced the timing of spawning of the intertidal bivalve *Macoma balthica*, resulting in a mismatch in timing between this bivalve and its phytoplankton food source. ■H

There is experimental evidence that warming can lead to declines in species-diverse intertidal zones and to take-over by competitive dominant plants, particularly at the southern range of diverse communities. ■M❋

Sand dunes, Saltfleetby - Theddlethorpe Dunes, National Nature Reserve, Lincolnshire © Natural England/Paul Glendell

What could happen

Projected rises in sea level will have significant impacts by accelerating the natural erosion of coastal and intertidal habitats, and by changing the pace and nature of natural geomorphological processes. Soft cliffs and the vegetation communities that grow on them will be particularly affected, especially in the south and east of England, where the land is sinking slightly. ■H

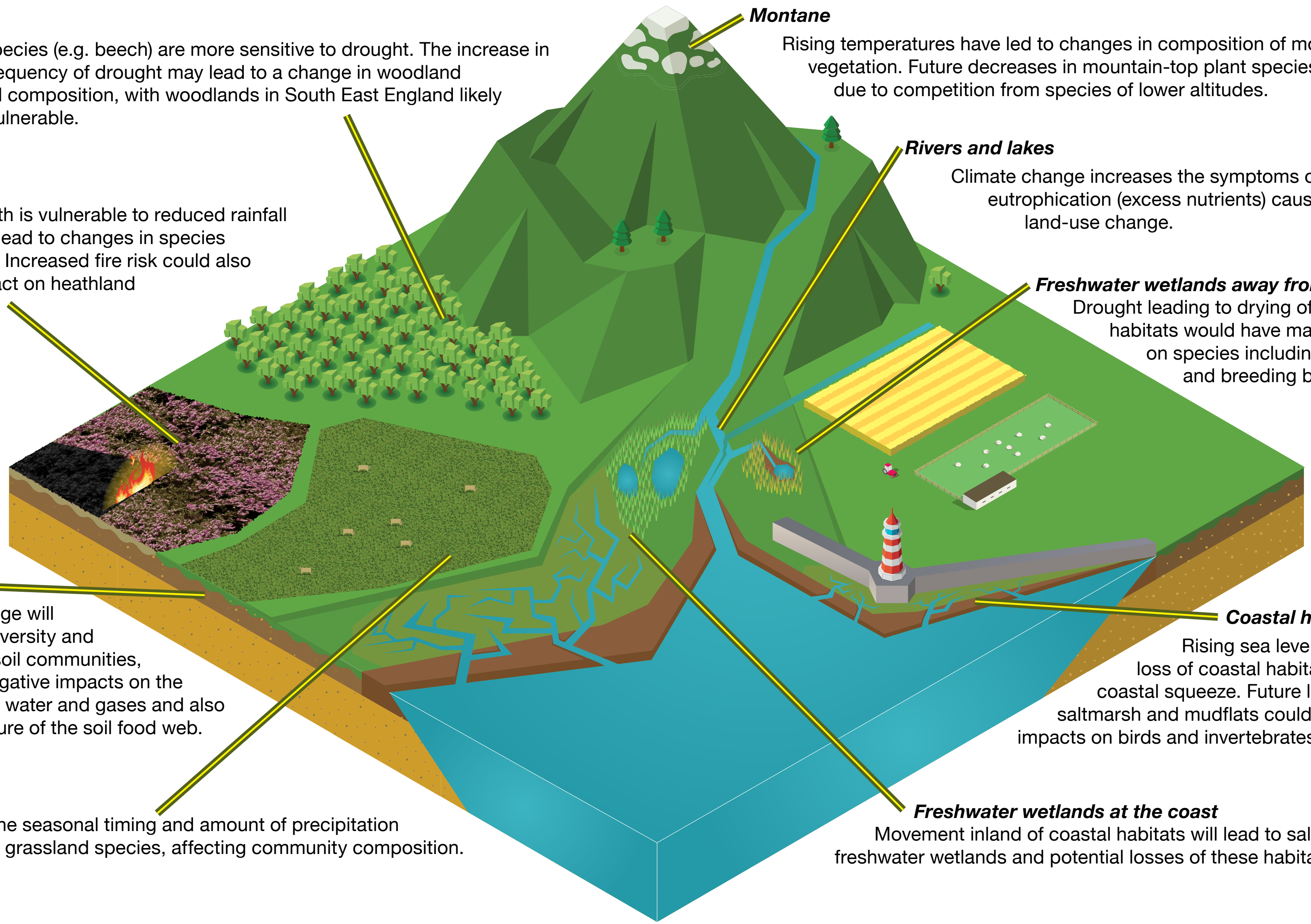
Rising sea levels will result in conflict between (i) the need to maintain intertidal and coastal habitats (e.g. dune systems) by allowing the natural movement of coastlines and through managed realignment and (ii) the need to protect valuable inland coastal habitats (e.g. grazing marsh, saline lagoons and freshwater coastal lakes). ■H

Coastal species and habitats will be subject to further coastal squeeze where coastal defences are maintained or enhanced or where hard infrastructure exists, preventing natural habitats rolling back inland. ■H

Projected future losses in the extent of saltmarshes and mudflats will have significant impacts on overwintering bird populations and the invertebrate that they support. ■H

Coastal grazing marshes, raised bogs and saline lagoons are all threatened by increases in salinity due to increased percolation and inundation of sea water during storm tides and flooding. This will ultimately cause their transformation into saltmarsh or other intertidal habitat. ■M

Increased winter rainfall could lead to the softening of the surfaces of cliffs and, when coupled with potentially higher water tables, could result in higher rates of cliff erosion. Increased winter rainfall may also lead to more frequent summer landslips as a result of groundwater movement. ■M❋



Woodlands
Some tree species (e.g. beech) are more sensitive to drought. The increase in severity or frequency of drought may lead to a change in woodland structure and composition, with woodlands in South East England likely to be most vulnerable.

Heathlands
Lowland heath is vulnerable to reduced rainfall which could lead to changes in species composition. Increased fire risk could also have an impact on heathland ecosystems.

Soil
Climate change will impact the diversity and structure of soil communities, leading to negative impacts on the movement of water and gases and also on the structure of the soil food web.

Grasslands
Changes in the seasonal timing and amount of precipitation could impact grassland species, affecting community composition.

Montane
Rising temperatures have led to changes in composition of montane vegetation. Future decreases in mountain-top plant species may result due to competition from species of lower altitudes.

Rivers and lakes
Climate change increases the symptoms of eutrophication (excess nutrients) caused by land-use change.

Freshwater wetlands away from the coast
Drought leading to drying of wetland habitats would have major impacts on species including migratory and breeding birds.

Coastal habitats
Rising sea levels lead to loss of coastal habitats through coastal squeeze. Future losses of saltmarsh and mudflats could have impacts on birds and invertebrates.

Freshwater wetlands at the coast
Movement inland of coastal habitats will lead to salinisation of freshwater wetlands and potential losses of these habitats.

There are 35 terrestrial mammal species, 12 reptile and amphibian species and about 300 bird species that are native to the UK. There are at least 24,000 species of insects in the UK, together with thousands of other invertebrate species that have not been quantified. There are nearly 3000 species of vascular plant (flowering plants, conifers, ferns, horsetails and clubmosses), over 1000 species of bryophyte (mosses, liverworts and hornworts), and around 2000 species of green algae in the UK. Climate affects each species individually but it is possible to identify some general patterns showing change in life-cycle events, population numbers and distribution and behaviour.

Birds

Pearce-Higgins

Evans & Pearce-Higgins

Gillingham

Moss

Morrison & Robinson

What is happening

Warmer winters in the 1990s and the early 21st Century increased the survival rates of many common and widespread resident bird species, contributing to population increases. ■H

Bird ranges in the UK have shifted northwards (by an average of 37km from 1990-2008) but have lagged behind changes in temperature. ■M

Snow Bunting © Natural England/Julian Dowse

Warming has been associated with an increase in the diversity of bird communities and particularly an increase in generalist bird populations. Populations of southern species have tended to increase more than those of northern species. ■M

70% of wetland bird species have shown a population decline since 2000 in both freshwater and estuarine sites; part of this decline is the result of changes to migration patterns in response to climate change. ■M✱

What could happen

Increased winter temperatures are likely to increase the overwinter survival rate and therefore the abundance of many bird species resident in the UK. ■L↓

Changes in summer rainfall and the consequences for soil moisture will affect many UK bird species by changing the abundance and availability of prey. Intense rainfall is likely to reduce the breeding success of many game bird or raptor species, especially those that nest on the ground or are open-cup nesters (e.g. the capercaillie and black grouse). ■M✱

Increased winter rainfall would reduce the overwinter survival of some small birds due to reduced prey availability and greater energy expenditure. ■L

Male and female kingfishers © Natural England/Julian Dowse

What is happening

Bird populations such as the song thrush, blackbird, ring ouzel and golden plover that rely on invertebrates associated with wet conditions are negatively impacted by increasing summer temperatures and drought. ■M

Goldfinch © Natural England/Allan Drewitt

What could happen

Species most associated with cool temperatures are likely to be most vulnerable to climate change, particularly those with a narrow thermal niche (e.g. the ptarmigan, dotterel and snow bunting are currently restricted to the summits of the highest Scottish mountains where suitable climatic conditions will disappear by the end of the century under many standard climate change projections). ■M

The breeding success of migrant species is likely to be negatively affected by warmer conditions between April and June, leading to feeding mismatches that will change the availability of invertebrates relative to these species' arrival time at their breeding grounds; this is particularly likely to affect long-distance migrant woodland species. ■L

Reptiles and amphibians

Dunford & Berry

Moss

Sparks & Crick

Changes in the timing of life-cycle events have been identified and related to increased mean temperatures. Monitoring of the common frog shows that congregation, spawning and hatching are happening earlier. ■H

Reductions in frog and toad populations are consistent with low summer rainfall and consequent lower soil moisture during the drier summers between 2003 and 2006, alongside loss of suitable habitats, habitat fragmentation and road mortality. ■M

Common Lizard © Natural England/Allan Drewitt

Modelling suggests that the area of climatic suitability for some reptiles and amphibians, including the smooth snake, natterjack toad and common toad, could expand; this could allow northward range expansion, although this will depend on their ability to move between habitat fragments. ■L

Common lizards, smooth newts and adders are projected to lose suitable climatic conditions across England under many climate change scenarios, but may expand their range in Scotland. ■L

Freshwater fish and other aquatic animals

Moss

What is happening

Cold-water fish communities are changing: the arctic charr is becoming scarcer as waters warm and it competes less well with the more thermally tolerant brown trout. ■M❋

Arctic Charr © FreshwaterLife/ Rob Holland

What could happen

In the lowlands, there is likely to be a decline in cold-water salmonids and an increase in warm-water cyprinids (e.g. the carp) that reproduce earlier. In particular, the carp is likely to expand its range northwards and breed more effectively; this is likely to be exacerbated due to its popularity with anglers. ■H❋

Coregonid fish (the schelly, powan, gwyniad, vendace and pollan) are currently in the southernmost part of their sub-arctic range (they are found in only a few lakes in Scotland, Wales and the Lake District) and will be increasingly threatened. ■H❋

There may be a decline in oxygen-demanding predators such as the pike and perch, resulting in higher survival of more fish that feed intensely on zooplankton; this will increase the level of algae and have negative impacts on shallow lakes dominated by vascular plants. ■M❋

Mammals

Newman & Macdonald

Juveniles are often more vulnerable than adults to extreme events (e.g. spring drought, flooding and cold winters); extreme events can therefore have a subsequent impact on mammal populations. ■M

Direct links have been found between summer rainfall and survival of bat species, with higher rainfall associated with greater insect abundance, and drier springs and summers having a negative effect. ■M

Mammals that rely on hibernation (e.g. hedgehogs, dormice and bats) are reducing their period of hibernation. Warmer winters mean that an animal's metabolic rates cannot remain suppressed effectively; this can reduce body condition, breeding success and survival rates. ■M

Breeding success and/or overwinter survival of mammals, including red deer, Soay sheep, badgers, rodents, rabbits and hares, tend to be higher during warmer winters. ■M

Mammals vary in their ability to respond to current average and extreme climatic conditions. This suggests that species will show a diversity of responses to climate change in the future. ■H

Harvest Mouse © Natural England/Allan Drewitt

What is happening

Periods of drought can reduce the survival of worm-specialist foragers such as badgers, moles and hedgehogs; persistent heavy rain can 'wash out' the flying insects that many bat species depend on. ■ M

Brown Hares © Natural England/Allan Drewitt

What could happen

Climate change may affect bat populations through changes in their yearly hibernation cycle, breeding success and food availability. ■ L

Reduced water flow in rivers would adversely affect mammals such as water voles and otters. ■ L

Milder winters could result in increasing populations of certain mammals (e.g. badgers) as a result of increasing food availability in the absence of freezing conditions and due to an earlier onset of spring. ■ L

Many mammals are vulnerable to climatic stressors at key stages in their life cycle (e.g. during the mating period, pregnancy, weaning, dispersal and hibernation); increased extreme events coinciding at these points will therefore have a disproportionate effect on these species. ■ L

Insects and other invertebrates

Mossman, Franco & Dolman

Pearce-Higgins

Gillingham

Pateman & Hodgson

Trends in many insect populations are influenced by variations in temperature and precipitation, but differ between species. ■ M

Climate warming has resulted in northward range shifts of many southern and common British invertebrates and changes in butterfly communities. ■ H

Climate change has benefited southern generalist butterfly species which have expanded their range. A number of northern upland butterfly species (e.g. the Scotch argus) have suffered recent declines in range through a combination of climate change and habitat loss. ■ M

The impact of changes in temperature and precipitation varies between butterfly species, with the negative effects of warm wet winters greatest in species that overwinter as caterpillars or pupae. ■ L

Although areas of climate suitability might increase for some species, not all species will be able to change distribution with changing climate, particularly in fragmented landscapes. ■ M

Some invertebrate species may change their habitat use through behavioural or evolutionary processes. For example, as a result of increases in temperature, the requirements of some warmth-loving species (including some butterflies such as the silver-spotted skipper) for sparse or short vegetation may be reduced and taller vegetation providing cooler, shaded microclimates may become suitable. ■ M

Changes in rainfall patterns (with more extremes) are likely to affect flight period and food availability for many insects; this may directly cause death, as well as having an impact on habitat quality, particularly in wetlands. ■ M

What is happening

Spring and summer life-cycle events are advancing, with earlier flight periods for spring species of dragonfly and damselfly, earlier appearance of some species of hoverfly, and extension of the mean duration of the aphid flight season by 3 days per decade. ■H

A number of invertebrates have colonised the southern UK from Europe in recent years and are expanding their range northwards. This includes flying species of Hymenoptera (wasps, bees and ants) and Odonata (dragonflies and damselflies) e.g. willow emerald damselfly. ■H

Silver-spotted Skipper © Natural England/Allan Drewitt

What could happen

Advances in emergence or flight date have the potential to lengthen the season suitable for reproduction; warmer temperatures may result in faster completion of insect life cycles at northern latitudes. This may lead to additional generations of insects, but there is no evidence relating to the viability of these in terms of access to food and vulnerability to occasional early frost events. ■L

Beautiful Demoiselle Damselfly © Natural England/Allan Drewitt

Plants and fungi (including lichens)

Sparks & Crick

Evans & Pearce-Higgins

Carey

Pateman & Hodgson

Ellis

Moss

There are fewer examples of recent changes in distributions that can be confidently attributed to climate change for plants than for animals, although there is evidence of an increase in southern generalist species and a decline in northern specialist species on Scottish mountains. ■H

Current flowering dates have advanced by 2-13 days over the last 250 years. ■H However, reduction in winter chill has delayed the flowering of some plant species. ■M

Local microclimates provide a buffer against macroclimatic change for some plant species, including bryophytes and lichens. ■M❋

As the extent of climate change increases, change is likely to start to become apparent in plant communities and species distributions. Montane and arctic-alpine species are threatened by climate change as more warmth-loving species colonise these habitats. Examples of plants extremely vulnerable to climate change include bryophytes (e.g. the arctic rustwort) and lichen-rich heath communities primarily found in Scotland, as well as those dependent on late-lying snow-beds. ■H

Warmer winters will benefit many plant species, increasing their abundance and allowing expansion into new areas. However, for some other species, winter warming will offset advances in spring green-up as winter chill requirements are not met for flower or seed development, reducing reproductive success. ■M

Plants and fungi (including lichens) continued

Sparks & Crick

Evans & Pearce-Higgins

Carey

Pateman & Hodgson

Ellis

Moss

What is happening

Aquatic plant communities are influenced by warming. One outcome is an increase in algae and cyanobacteria in the water, leading to shading and a decline in bottom-growing species whilst floating species (e.g. duckweed and introduced species) become more prominent. ■M✱

Pasqueflower © Natural England/Peter Wakely

What could happen

Long-lived perennial plants dominate UK flora and this longevity means that climate change impacts and measurable changes in population sizes and geographic distributions (e.g. changes in seed production or seedling survival) take many years to be reflected in the adult population. ■M✱

Plants flowering at the end of summer may be relatively more vulnerable to the impacts of drought and heat stress. ■L

Early emergence of vegetation driven by climate change may increase the risk of exposure to frost damage if spring vegetation emergence advances more quickly than that of the last frost dates. ■L

Warmer temperatures and extended growing seasons will lead to more reliable and frequent fruiting of some southern plant species near their northern limits (e.g. the small-leaved lime. ■M

Climate change may reduce persistence of seeds in the soil by increased exposure to soil moisture and warm temperatures during winter. ■L

Dryad's saddle fungus © Natural England/ Paul Glendell

The impacts of climate change on biodiversity result from a series of interactions between organisms and their environment and with each other. Research has unravelled some of these mechanisms of change and it is important to understand them to anticipate future changes reliably. There has been increasing recognition of the importance of this system-level understanding and the importance of understanding the role of people within ecosystems. Climate change will affect the provision of ecosystem

Soil and water

De Vries & Bardgett

Doswald & Epple

Moss

Evans & Pearce-Higgins

What is happening

Soil processes such as nitrogen mineralisation, litter decomposition and soil respiration are sensitive to temperature and soil water content. This sensitivity results from changes in the composition and metabolism of soil communities and vegetation. ■H❋

Increases in atmospheric carbon dioxide tend to increase plant photosynthesis and growth, including the level of available biomass. This in turn increases the abundance of fungi and the abundance and body size of most groups of fauna; it has limited impacts on bacterial diversity. ■L❋

Drought directly impacts soil fungi and bacteria; but by leading to changes in plant litter and root growth, it also decreases the biomass and abundance of most microbial and soil fauna groups. ■H❋

Extreme events, particularly drought and wildfire, can lead to the loss of significant amounts of carbon from vegetation and soils, especially on peatlands. ■H

Effects of rainfall and flooding on soil organisms are context-specific but result in soil compaction, increased run-off of soil nutrients and soil anaerobicity (i.e. lack of oxygen); this leads to loss of soil's structural stability and of nutrients from the soil. ■L

Left image: Sphagnum carpet, Blackslade Mire
Right image: Flooded peat workings from Avalon Lakes, Shapwick Heath © Natural England/Peter Wakely

What could happen

Climate-driven changes in the diversity and structure of soil communities will affect soil processes and physical properties (e.g. its porosity, which is increased by the action of earthworms). ■H❋

Increases in rainfall could lead to increased leaching of nutrients, changing plant community composition and causing nutrient enrichment of freshwaters. ■L❋

Changes in climate have the potential to increase or decrease carbon storage and sequestration, depending on local circumstances, timescale and the relative importance of rising temperatures and other aspects of climate. ■H

Frequent periods of high and low flow in hydrological systems will increase concentrations of nutrients and biological and chemical contaminants. This will increase the value to society of ecosystem processes that improve water quality. ■M

Shallow-water bodies may experience rapid temperature increases during periods of hot weather, which may lead to oxygen depletion and blooms of blue-green 'algae' (cyanobacteria). ■M

What is happening

Species interactions

Evans & Pearce-Higgins

Mossman, Franco & Dolman

Pearce-Higgins

Newman & Macdonald

Moss

De Vries & Bardgett

A range of experiments has shown that changes in climatic factors affect the growth rates of plant species, altering interactions between species and also community composition. ■M↓

Climate change can alter the impact of plant-eating insects on vegetation by increasing the insect population or changing the relative timing of insect emergence; for example, higher temperatures appear to increase the aphid population, with subsequent impacts on vegetation. ■M

Increased plant growth rates or increased exudation of liquids from plant roots, as a result of warming and increased carbon dioxide can affect the activity and composition of below-ground organisms. ■H✱

Climate-driven mismatches in the phenology of plants and their pollinators have been observed but there are no observations of climate-driven mismatches between these species due to changes in distribution. ■M

Orange Tip © Natural England/Allan Drewitt

What could happen

Temperature increase, increased frequency of droughts and floods and increased carbon dioxide will all result in significant changes in many plant communities, as well as in the composition of soil microbial communities and soil food webs. ■H✱

Range shift and species colonisation are likely to give rise to novel combinations of species and complex changes in food web interactions between, for example, plant species and herbivores, parasites and hosts. ■M

Further changes in climate will increase the risk of a breakdown in the synchrony between different species' life-cycle events. Food chain mismatches are most likely in highly seasonal species that depend on a synchronised food peak; the link between abundance of caterpillars and the reproductive success of woodland birds is one example of the importance of such synchrony. ■M

Changes in climatic conditions will alter the way that different species compete for the same resources (e.g. food or living space) in an ecosystem, leading to shifts in species composition. The greatest impacts and changes are likely at the southern range margins of northern species. ■M

Although potential exists for mismatches between flower production and peak pollinator availability, there is considerable flexibility in which species pollinate most plants; this could buffer the majority of plants from mismatches (at least in diverse communities). ■L

Elephant hawkmoth caterpillar © Natural England/Paul Lacey

Genetic diversity and potential for genetic adaptation

Neaves *et al.*

What is happening

Populations of many species are genetically adapted to local conditions, including climate. ■M

Climate-driven changes in phenology, species distributions and population sizes are already altering the amount and distribution of genetic diversity (i.e. the variation of genes found within a population or species, which represents the raw material for natural selection). ■M

Rapid genetic adjustments to warming have been observed in zooplankton and fish in freshwater systems, and are also likely to be occurring in other invertebrates and microorganisms. ■L❋

Genetic variation in some populations is enabling adaptive responses to environmental change; for example, the brown argus butterfly has started to use a new plant food, wild geranium. ■L

Genetic diversity is being reduced in many species. This increases the risk of inbreeding depression, reduces survival of individuals and restricts opportunities for evolutionary adaptation to changing conditions. These factors can exacerbate extinction risk. ■M❋

Brown Argus butterfly © Natural England/Allan Drewitt

What could happen

The rate of evolution will be unlikely to match climate change where genetic diversity is low, gene flow between populations is restricted, reproduction rates are low or generation times are long. ■M

Evolutionary (genetic) adaptation to climate change will allow some populations to persist where the climate would otherwise become unsuitable, or to colonise new areas. ■M↑

Heavily fragmented landscapes that reduce gene flow between populations will hamper genetic adaptation to new conditions even in some widespread species. ■M

River Frome at Tincleton, Dorset © Natural England/Peter Wakely

Pests and diseases

Doswald & Epple

Evans & Pearce-Higgins

Hulme

Mossman, Franco & Dolman

Newman & Macdonald

What is happening

Increases in temperature contributed to the spread of bluetongue virus in the UK. The virus is carried by the biting midge *Culicoides imicola*, a southern European species, which is currently spreading north. Deer suffer from and act as wildlife reservoirs for bluetongue and other midge-borne diseases. ■M

There has been an increasing incidence of tick-borne diseases, notably Lyme disease which is carried by a range of mammal species and is extending its distribution further northward. ■L❋

What could happen

Climate change will increase the number of potential plant diseases due to a northward range expansion of pathogenic organisms and their vectors. ■H

Climate change will increase the suitability of the UK climate for a number of non-native forest pathogens (including ones that affect a wide range of native plant species), such as thermophilic (warmth-loving) rust fungi. ■H

Rising temperatures will make the climate in the UK suitable for an unknown number of invertebrate pests whose dispersal will be helped by international trade, particularly the timber and horticultural trade. ■L

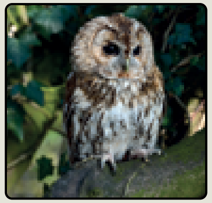
Milder winters and greater food availability are associated with more abundant rodent populations; this could increase the risk of diseases that can be spread between animals and humans, such as toxoplasmosis and Q-fever, especially during periods of extreme rainfall. ■L❋

Climate change may contribute to declines in bird populations by increasing the effects of diseases and parasites. The size of this risk is only known for red grouse, where a gastro-intestinal nematode is likely to increase in warm, wet conditions, leading to a reduction in red grouse fertility and abundance. Together with impacts of heather beetle on heather, this may have consequences for game shooting on grouse moors. ■L

Thermophilic Rust fungus on Norway spruce © Forestry Commission/Barry Lambsdown

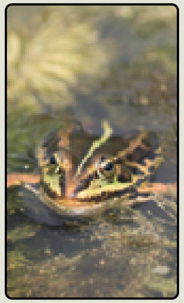
Examples of observed climate change impacts around the UK

Range retractions have been recorded for species of ***upland butterfly*** in response to climate change, for example the ***mountain ringlet.***

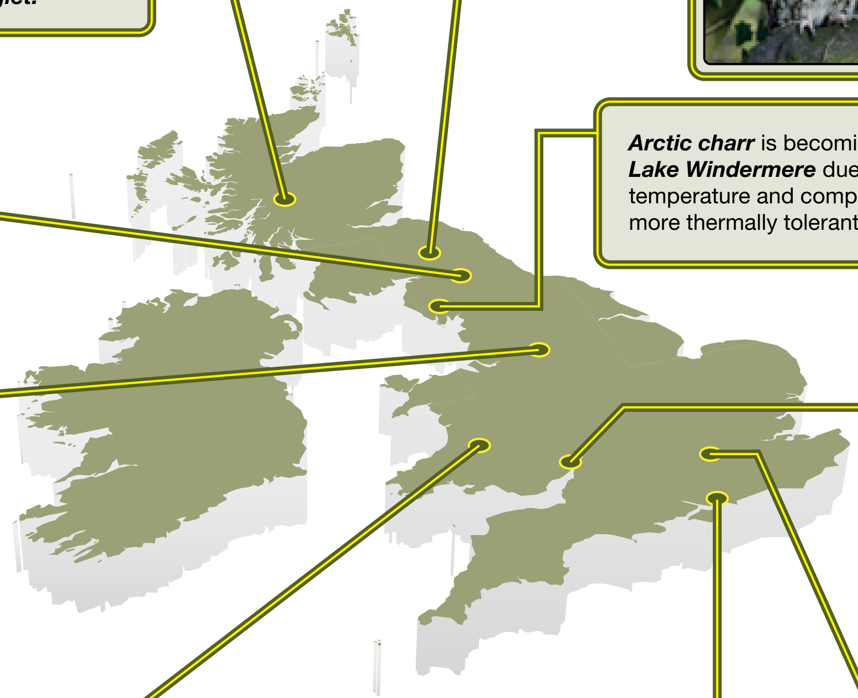


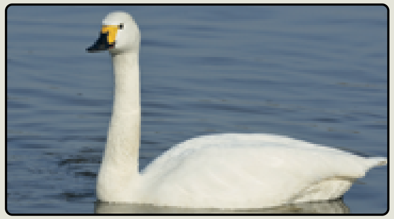
Breeding success of ***tawny owls*** in ***Kielder Forest*** is being reduced by the impacts of warmer, wetter winters on dampening the population cycles of their prey species, voles.

First spawning dates for ***frogs*** have varied across years but equate to more than a 5 day advance for every 1°C increase in air temperature. A study in the ***Northern Pennines*** found evidence supporting this change.



Arctic charr is becoming scarcer in ***Lake Windermere*** due to increasing temperature and competition with more thermally tolerant species.





Wintering wildfowl and wader species, such as Bewick's swan, have declined significantly in abundance in the UK; this decline is particularly evident in ***west coast estuaries*** as milder winters reduce the distance they migrate.

Fluctuations in breeding ***golden plover*** populations in the ***Peak District*** are linked to changes in cranefly populations (a key prey) caused by temperature changes and drought.

Long-term data from 1981-2005 for the ***Llyn Brianne*** experimental catchments in South Wales highlight the sensitivity of ***invertebrate community*** in ***headstreams*** to climatic effects, suggesting altered composition and reductions in abundance.

Rising sea levels have contributed to the losses of ***salt marshes*** at the coast, with estimates of 50% losses on the south coast over 30 years (1971-2001).

First leafing dates for ***oak*** trees in ***Surrey*** were recorded from 1950-2015. An advance of 3-4 weeks has been observed.

References: Mountain ringlet/upland butterfly – Franco A.M.A. et al 2006. Global Change Biology, 12, 1545-1553; Tawny owl/Keilder – Millon A. et al 2014. Global Change Biology, 20, 1770-1781; Golden Plover – Pearce-Higgins J.W. 2010 Climate Research, 45, 119–130; Bewick's swan – Evans K. and Pearce-Higgins J. 2015.Biodiversity climate change impacts report card technical paper 14; Frog – Scott W A. et al 2008. Journal of Herpetology, 42, 89-96.; Arctic charr – Moss B. 2015 Biodiversity climate change impacts report card technical paper 17; Oak trees – data courtesy of the Woodland Trust; Llyn Brianne, Wales – Durance I. & Ormerod S. J. 2007. Global Change Biology, 13, 942–957; Saltmarsh, south coast – Baily B. & Pearson A.W. 2007. Journal of Coastal Research, 23, 1549-1564.

There is clear evidence that changes in the UK's natural environment consistent with climate change are already happening and are likely to increase in future. In the spheres of both science and policy, the need for adaptation to climate change is well recognised.

There are three main elements to adaptation:

- **Building resilience to climate change.** Evidence has strengthened in recent years that the vulnerability of species populations to climate change is influenced by the way land is used and managed. As a result, there is scope to use land management to reduce risks to the UK's biodiversity. Protected sites are a critical element: species preferentially colonise sites in designated conservation sites when expanding northwards and persist in them longer at their southern range margins. Initiatives to develop 'ecological networks' at the landscape scale can also contribute to building resilience by allowing species to survive within and disperse across the farmed environment. Larger areas of semi-natural habitat increase the resilience of populations to extreme events, while there is new evidence that microclimate differences may allow species to persist locally and that this can be exploited to promote resilience.
- **Accommodating change.** Many local changes cannot be prevented and greater flexibility will be needed to protect biodiversity at the UK scale. Protected sites will remain important elements of conservation but the species they support may well change. This will need to be taken into account when setting objectives for site management. In some cases – and most conspicuously in coastal areas – habitat losses may be balanced by the creation of new habitats elsewhere. Some species may benefit from greater connectivity of semi-natural habitats, allowing them to disperse to new locations; this needs to be considered alongside measures to improve protected sites.
- **Ecosystem-based adaptation.** Understanding of the benefits that the natural environment provides for society has increased in recent years. The natural environment can be managed in ways that both help people to adapt to climate change and support biodiversity. This includes reducing flood risk through catchment management, such as re-naturalising water courses and creation of wetland areas; successful schemes of this sort have already been introduced. Evidence also exists that vegetated areas in cities can reduce local temperatures during heat-waves.

The balance between these three different elements will vary across the UK. In situations where major change is already occurring and we have high confidence that climate change will be an ongoing threat, specific adaptation actions should be prioritised to avoid serious negative effects. This may include accommodating change. In other situations, where evidence and confidence are low, building ecological resilience in a generic way and improving monitoring can provide the basis for a flexible adaptive management strategy that can be updated once improved evidence has become available.

Further advice on climate change adaptation for biodiversity

Adaptation is the focus of active development work and the following resources provide a good introduction as well as guidance to the subject:

- National Adaptation Programme (NAP)
- Climate Ready support service (provided by the Environment Agency)
- Welsh, Scottish and Northern Ireland Adaptation Programmes
- Adaptation Scotland
- Climatic Change and the Conservation of European Biodiversity: Towards Adaptation Strategies
- Climate Change Risk Assessment (CCRA)
- Natural England and RSPB Climate Change Adaptation Manual
- Lawton Review: Making Space for Nature
- Climate Change and Nature in Scotland

The evidence summarised in this Report Card provides a key input to the UK Climate Change Risk Assessment (CCRA). The CCRA is a statutory requirement of the Climate Change Act (2009), providing a synthesis of the key risks from climate change (present and future) and recommendations for adaptation priorities. The NAP (and its equivalents for Scotland, Wales and Northern Ireland) uses the information from the CCRA to develop a structured programme of actions to manage climate change risks.

The review paper by Oliver and Roy presents evidence on the interactions between land use and climate change and that by Gillingham considers protected areas.

Confidence assessments and causes of change

A core requirement when presenting climate change impacts is to communicate how much confidence we can have in any particular piece of evidence. This is key to determining the priorities for action and the measures to be taken. In some cases, evidence surrounding an important issue may have low confidence and this may suggest that improved monitoring data should be collated before action is taken. Similarly, high confidence in evidence provides a strong foundation for action. In the context of decision-making, assessment of confidence should form part of a wider risk assessment that also considers the seriousness of a potential change and the practicalities of addressing it.

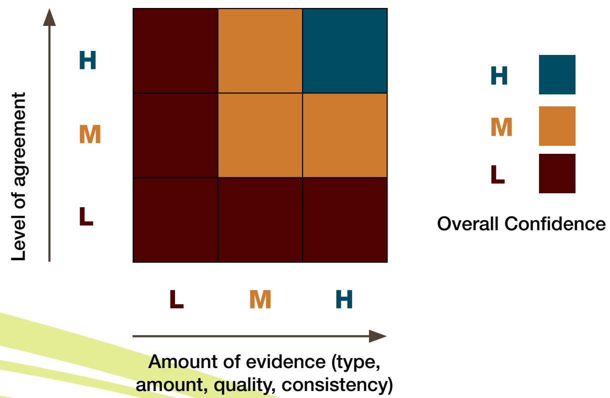
During the production of this Report Card, contributing authors were asked to provide a confidence assessment for each of the headline messages included in their technical papers. A version of the confidence scales developed by the Intergovernmental Panel on Climate Change (IPCC) was used to capture the amount and quality of the evidence supporting the statement and the level of agreement between different sources. Confidence increases where there are multiple, consistent, independent lines of high-quality evidence.

Our understanding of what is already happening is based on current and past observations. Our ability to detect trends in the data is determined by the amount of data available and how representative it is. If there is very little data, or the data is only for one part of the country, confidence in the observation is low compared to a national dataset that has been collected over many years. The UK has arguably the best monitoring data in the world for a wide range of different species and habitats. There is particularly good data for birds and butterflies, and the timing of life-cycle events such as egg laying and flowering of plants has been well recorded. However, some other groups, including some mammals, are relatively poorly recorded, making it more difficult to be confident about identifying trends, and the findings presented here reflect this.

A further complication is that a range of non-climatic factors are also affecting the natural world, including changes in land use and management, air pollution and both animal and plant diseases. Scientists therefore have to take account of the probability that climate, rather than one of these other variables, is the cause of change. Gathering evidence that climate is the cause of change includes understanding the processes by which climate affects plants and animals, and testing other plausible causes of change. A range of ‘field experiments’ which artificially raise temperatures or manipulate water supply to plots of vegetation also make it possible to test empirically the effects of climate on biological communities and soils.

In assessing the effects of past and present changes in climate, this Report Card focuses on the relationship between observed changes in meteorological data and in biological data. It does not address the causes of climate change itself – for example, the relative importance of greenhouse gas emissions and natural causes – which have been extensively dealt with elsewhere.

The descriptions of potential future change are based on a variety of types of evidence including (i) understanding of the mechanisms by which climate affects plants and animals, (ii) field experiments (see above) and (iii) a variety of computer models. They are qualitative assessments that indicate a direction of travel rather than quantitative predictions. Although climate models project changes in temperature with reasonable confidence, the complexities of ecological responses and the interactions with other non-climate pressures mean that there is a large range of possible future outcomes. This is compounded for other climate variables (e.g. rainfall) where there is less certainty in future projections. This publication includes examples of ecological sensitivity as a way of understanding a range of plausible scenarios.



The Report Card has simplified the assessments to provide an overall confidence level of high (H), medium (M) or low (L). Low confidence results are still based on evidence and still reflect expert judgment. Since producing the last version of this card, we have adjusted the assessment slightly so that where there is only a low amount of evidence, confidence is considered to be low regardless of whether there is a high level of agreement.

Technical papers and contributors

This Report Card is a summary of 17 technical papers commissioned from leading experts, with each paper presenting a literature review of current scientific research and evidence for the topic it addresses. Some of the papers were originally prepared in 2013 but have been updated and reviewed for the 2015 Report Card. These papers, which include supporting evidence and sections on knowledge gaps and confidence assessments can be accessed from the links below.

Technical papers 2015

1. Oliver T., Roy D., Interactions between climate change and land-use impacts: addressing attribution problems
2. Newman C., Macdonald D., Implications of climate change for UK mammals
3. Mossman H., Franco A., Dolman P., Implications of climate change for UK invertebrates (excluding moths and butterflies)
4. Gillingham, P., Implications of climate change for SSSIs and other protected areas
5. Carey, P., Impacts of Climate Change on Natural and Semi-Natural Vegetation
6. Pateman, R., Hodgson, J., The effects of climate change on the distribution of species in the UK
7. Pearce-Higgins, J., Evidence of climate change impacts on populations using long-term datasets
8. Ellis, C., Implications of climate change for UK bryophytes and lichens
9. Hulme, P., Non-native species
10. Mossman, H., Grant, A., Lawrence, P., Davy, A., Implications of climate change for coastal and intertidal habitats in the UK
11. Morrison C., Robertson R., Implications of climate change for migration
12. Sparks, T., Crick, H., Implications of climate change for phenology in the UK
13. Doswald, N., Epple, C., Overview of climate change implications for ecosystem services
14. Evans, K., Pearce-Higgins, J., Mechanisms driving UK biodiversity responses to climate change: assessment and indicators
15. Neaves, L., Whitlock, R., Piertney, S., Burke, T., Butlin, R., Hollingsworth, P., Implications of climate change for genetic diversity and evolvability in the UK
16. de Vries, F. & Bardgett, R., Climate change effects on soil biota in the UK
17. Moss, B., Freshwaters, climate change and UK conservation

Dunford R. & Berry P. Climate change modelling of English amphibians and reptiles: Report to Amphibian and Reptile Conservation Trust (ARC-Trust)

Working Group

Delivery of this Report Card was overseen by a Working Group which also undertook peer reviews of the technical papers.

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