The nature of climate change
Europe's wildlife at risk
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Foreword

We are at a point in recent geological history where the rate of human-induced climate change will far outstrip the ability of species to adapt successfully, especially when the resilience of nature has been reduced by habitat loss, non-native species introductions and over-exploitation. The disruption to the web of life is a threat not just to wildlife, but to the lives of people around the world.

This report presents the evidence that wildlife in the UK and beyond is already facing a more challenging time due to the climate change that has occurred; and that things are, for the most part, only likely to get worse. Higher rainfall will likely have a detrimental effect on bearded tits, capercaillie and shags for example, and warmer temperatures in southern Europe will result in habitat loss for Dartford warblers. Moreover, the evidence points to global scale patterns of change, such as the collapse in kittiwake populations linked to sea surface temperatures and the timing of plankton blooms. Of course it’s not all bad news, and we’ve already seen exciting new species colonise the UK and begin breeding here, some of them on our very own RSPB reserves. Birds like little egrets, black-winged stilts and little bitterns are spectacular and enticing new arrivals.

But we have to face up to the fact that in general the changes to our climate will be challenging for wildlife. One of the most important conclusions of this report is that protected areas and nature reserves will be vital in the future for helping wildlife to cope with climate change. This makes it even more important that we ensure EU decision makers leave the Birds and Habitats Directives intact and that they are better implemented.

Protecting wildlife from these threats means each country, in Europe and in the UK, playing an active role in mitigating carbon emissions. We need a clear policy direction to keep rolling out renewable energy that doesn’t harm nature, and to invest more in ways that benefit the climate and help nature and people to adapt, such as by restoring our upland peatlands.

Nature is demonstrating that we’re already into the world of change. This report has a clear message – we need to act, and fast, to reduce our greenhouse gas pollution and to face up to the impacts we’re already living with. Then we can make better homes for nature, and ourselves.

Dr Mike Clarke
Chief Executive
The RSPB
1) The impacts of climate change on wildlife

Background and purpose of the report

Human actions are causing the climate to change extremely rapidly. Since the Industrial Revolution, global temperatures have risen, driven by rising greenhouse gas concentrations in the atmosphere\(^1\). Comparison with historical records suggests that temperatures are rising at an unprecedented rate\(^2\). It is very likely that temperatures will continue to rise throughout the 21st century: we are committed to further climate change\(^3, 4\).

**Climate change is already changing the natural world.** Plants and animals are adapted to certain climatic conditions that they require to survive and thrive. As the climate changes, becoming more or less favourable, species will be impacted by, and will have to respond to, the new conditions. There is abundant evidence of this already occurring. This report aims to document some of the impacts of climate change on wildlife that we’ve already seen, changes we might expect in the future, and some of the possible conservation responses that could benefit both wildlife and people.

**The focus of this report is on areas where the RSPB has taken a closer role in understanding, limiting or managing the impacts on wildlife. This may have been via on-the-ground conservation action, leading scientific research, or collaboration with other researchers.**

The scale of climate change means we must think beyond national boundaries, so this report considers wildlife throughout Europe. Because entire ecological communities are experiencing the effects of climate change, it considers species from plankton and plants, through to insects and other invertebrates, up to birds and mammals.

**Structure of the report**

The report is structured in themed sections. In each section, examples are presented from the wider scientific literature to illustrate the impacts already occurring and those expected in the future. Each section also provides more detailed case studies focusing on the science and conservation work to which the RSPB has contributed. Together, these examples show how climate change is driving fundamental changes to wildlife, and how conservation action can continue to help wildlife to adapt.

Within individual plants and animals, genetic, physical and functional changes have been detected; within populations of individual species, changing abundances and changes in geographic distribution are increasingly observed; within entire ecological communities, changes in the species present and in food web functioning have been documented\(^5\). Responses to the warming climate are complex: if one species in an ecological community changes, there will be knock-on impacts for others, leading to ecosystem-scale impacts\(^6\).
It is essential that we understand these impacts of climate change on wildlife, so that appropriate conservation measures can be taken. As the area with suitable climate for species changes and shifts, species may move into new areas (section 2 – from page 6, and section 3 – from page 10) to track suitable climatic conditions. In a given area, abundances of some species will increase whilst others will decline, and species new to the area will establish populations, leading to big changes in ecological communities (section 4 – from page 13). As interactions between species (section 5 – from page 17) are altered, reduced prey abundance, increased predation risk, or new diseases and pathogens could prove to be substantial threats. As the intensity and frequency of extreme weather (section 6 – from page 21) increases, wildlife populations could suffer severe mortality or reproductive failure. Climate change therefore poses a threat to biodiversity, and will change the biological communities with which we are familiar.

Future projections (section 7 – from page 24) suggest that further, substantial changes will occur, potentially bringing increased risk of extinction, so nature conservation also needs a longer term outlook. We need to consider how vulnerable, sensitive and exposed species are – and will become – and assess how different conservation methods might help. Existing conservation methods will be vital. Protected area networks (section 8 – from page 28) are essential to help species survive and track suitable climate. Site management (section 9 – from page 31) and creation of new sites (section 10 – from page 35), to aid population resilience and accommodate changes, will also help species to adapt. Landscape-scale approaches will help link sites, and encourage ecosystem-based adaptation (section 11 – from page 38) that benefits both people and wildlife. Finally, the report concludes with the implications for conservation (section 12 – from page 42).
2) Shifting ranges

Many species are already moving, predominantly northwards and to higher elevations. This is exactly what we would expect as a response to a warming climate.

Climate is important in determining where a species can live – its range. Species are adapted to particular climatic conditions, but as global temperatures rise, the conditions they experience are changing. Some species may tolerate the change at a location, by rapid adaptation. However, given the unprecedented pace of current climate change, many species will need to move to track the conditions suitable for them.

The climate shows natural gradients: broadly-speaking, it is warmer near the equator, cooler near the poles, and cooler at higher elevations. A species has a natural range, often bounded at higher latitudes or elevations where it becomes too cold for the species, and at lower latitudes or elevations beyond which it becomes too warm. Even if a thermal limit is not reached, a species’ range may be bounded by other factors such as moisture availability, habitat suitability, or availability of land. As temperatures rise, lower latitudes and elevations of a species’ range could become less climatically suitable, while higher latitudes and elevations (if available) could become more suitable. If species track these changes, their ranges will shift toward the poles (ie northwards in Europe) and uphill.

One way to study this is to examine changes in the most extreme northerly points of a species’ range – the northern range margin. As the climate warms, areas further north are being colonised, shifting the northern range margin. Across 59 British bird species, this margin shifted north by an average of 19 km between 1968–72 and 1988–91\(^{11}\). Further shifts happened between 1988–91 and 2008–11, with the northern range margin of 77 species moving north by an average of 13.5 km\(^{12}\).

Even larger shifts have been observed. Between the 1960s–70s and 1980s–90s, the northern range margins of many British animals, including mammals, grasshoppers, beetles and spiders, shifted north by an average of 12.5–19 km per decade\(^{13}\). An updated analysis indicated that across 1,573 British species from 21 groups, including birds, bees, dragonflies and moths, the northern range margin shifted 23.2 km per decade on average between the 1960s–70s and 1980s–90s, and a further 18.0 km per decade between the 1980s–90s and the 2000s\(^{14}\). Similarly, another analysis found that 24 British dragonfly and damselfly species moved an average of 88 km further north between 1960–70 and 1985–95\(^{15}\). In France, the pine processionary moth – a species that causes severe damage to pine trees – advanced 87 km between 1972 and 2004\(^{16}\).

Conversely, populations at the southern range margin face the risk of local extinction. For instance, two butterfly species of northern Britain, the northern brown argus and scotch argus, showed southern range margin retractions of 70–100 km between the 1970s and late 1990s, driven by local extinctions in southerly sites\(^{17}\). Likewise, between 1960–70 and 1985–95, southern range margins of northern British dragonflies and damselflies shifted 44 km north on average\(^{15}\). However, overall, fewer southern range margin shifts have been observed so far. This is perhaps because complete disappearance from an area is harder to confirm or
because other factors, such as species interactions or habitat availability, are currently more important determinants of population persistence at southern margins\textsuperscript{15}. 

As a result of these expansions and retractions, \textit{species’ entire ranges are shifting}. The most dramatic examples of this are in the sea. Plankton species found in the Bay of Biscay and waters around the south-western UK in the 1960s were, by the 1990s, found approximately 1,100 km further north, around northern Scotland\textsuperscript{18}. Fifteen North Sea fish species, including commercially-fished species such as cod, moved an average of 170 km north (ranging 48–403 km) between 1977 and 2001\textsuperscript{19}. On land, between 1981 and 2000, wintering distributions of grey plover and curlew in north-west Europe shifted 115 km and 119 km north-east, respectively\textsuperscript{20}, whilst for 122 British breeding bird species, the central point of their distributions shifted an average 20.4 km north between 1988–91 and 2008–11\textsuperscript{12}. 

\textbf{There is also good evidence for changes in the elevations over which species occur.} Four northern British butterfly species moved an average of 41 m (metres) uphill between 1970 and the late 1990s, because of local extinctions at lower sites and colonisation of higher sites\textsuperscript{21}. In the Alps, dung beetles moved uphill 65 m on average between 1992–93 and 2007, mainly by colonising higher locations, whilst in the Spanish Sierra Nevada mountains, they shifted 321 m uphill between 1981–82 and 2006–07, driven by both colonising higher elevations and loss from lower elevations\textsuperscript{22}. In the Sierra de Guadarrama mountains in Spain, the lower limit of 16 butterfly species moved uphill by an average of over 200 m between 1967–73 and 2004, but the upper limit was unchanged, so the overall range shrunk\textsuperscript{23}. In the sea, however, temperatures are higher closer to the surface: consequently, 28 bottom-dwelling fish in the North Sea moved an average of 3.6 m per decade deeper between 1980 and 2004\textsuperscript{24}. 

In some cases, rapid \textit{changes in species’ behaviour or form appear to have facilitated range shifts linked to climate change}. For instance, in Britain, northern expansion of the brown argus butterfly has been driven by greater use of a widespread geranium species for egg-laying, so the extent of suitable breeding habitat has increased\textsuperscript{25}. Some changes are even more fundamental. Northward shifts of the garden tiger moth\textsuperscript{26} and a species of bush cricket\textsuperscript{27} in Britain have been associated with changes to their wing shapes, which are linked to improved dispersal capability. 

Species are moving as we would expect in response to climate change, showing that, by moving to new areas, they can adapt to changing conditions. However, whilst shifting ranges could aid species’ persistence in the longer term, \textbf{not all species are responding adequately to the changing climate}. In Finland, 48 butterfly species shifted their northern range margin an average of 60 km between 1992–96 and 2000–04, but the shifts were smaller for species that were threatened or less mobile, with these traits likely to mean that the species’ required habitats were too rare and patchy, or too hard to reach\textsuperscript{28}. In the North Sea, larger fish species and those that reached reproductive age later were less likely to shift ranges in response to warming\textsuperscript{19}. In the Alps, breeding birds shifted uphill between 1992–94 and 2003–05, but the changes were small and less than expected from observed temperature increases\textsuperscript{29}. In Sweden, of 101 breeding bird species, around 20% showed range shifts in the direction expected, but many did not fully compensate for the extent to which temperatures had increased\textsuperscript{30}. While some variation in ability to respond is due to variation between the species themselves, for instance in specialism or dispersal ability, \textbf{a key factor is}
availability of suitable habitats: a species can only shift range if there is suitable habitat to move into (see sections: on Protected areas, from page 28; Site management, from page 31; and Creating new sites, from page 35).

**Case study: Dartford warbler range change (Wotton et al., 2009; Bradbury et al., 2011)**

The Dartford warbler is a bird species of dense, low scrub in Western Europe and North Africa. At the northern extent of its global range in southern Britain, where it is a heathland specialist, the climate is only marginally suitable. In 1963, following two very cold winters, the population may have declined to as few as 11 pairs.

National surveys for the species from the 1970s to the 2000s showed major changes. Protection afforded by the 1979 EU Birds Directive enabled the population in the species’ core area to increase, and new areas were colonised. These areas included sites at higher elevations and further north, suggesting winters were no longer so strongly limiting: higher temperatures have aided the Dartford warbler’s northward expansion. Severe winters in the late 2000s led to some population declines, but the Dartford warbler has recovered well and maintained the range extension, with further expansion likely in the coming years.

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Dartford warbler distributions from UK national surveys. White spots show population of 1–4 territories, yellow shows 5–14 territories, orange shows 15–49 territories and red shows over 50 territories. Over time, the population has grown and spread north and west.

Adapted from Wotton et al. (2009), British Birds 102(5), 230–246.
However, the UK range expansion as temperatures rise tells only part of the story. In Spain, the core of its range, the Dartford warbler is declining, likely through habitat loss\textsuperscript{34}. Models of future climate change suggest that during the 21st century, the climate will become unsuitable for them across large parts of their southern range\textsuperscript{35}. Therefore, \textbf{whilst climate change could lead to the Dartford warbler increasing in Britain, its global future may be less positive.} This highlights the importance of coordinated, continent-scale action to support wildlife adaptation.
3) New arrivals

*Species are starting to successfully colonise new territories as they track suitable climate. Conservation strategies will need to support this.*

As the climate changes, populations of species are establishing in areas where they are not known to have occurred previously. Many range shifts discussed in the previous section considered how species moved within a territory: British birds, Finnish butterflies, North Sea fish. However, species moving tens or hundreds of kilometres in a decade will inevitably arrive in areas where they are not “native” species: they will have colonised a new region or country. Observing these colonisations, understanding them and providing suitable habitat for range expansion are key parts of the conservation response to climate change.

The UK provides good opportunities to study colonisation: as a series of islands supporting well-studied wildlife, incoming species are often well-recorded. These records have been used to examine the occurrence of over 7,000 species from a range of groups, including plants, spiders, butterflies and moths, freshwater fish, birds and mammals: since 1900, at least 120 species have colonised Britain. Over time, the number of species colonising Britain has increased, as we would expect if the warming climate was responsible, although other factors, such as global trade, are also important.

Some of the best-known recent colonists of the UK are waterbirds. Since 2008, there have been first breeding records for cattle egrets, purple herons and great white egrets, the commencement of regular breeding by little bitterns, and breeding attempts by black-winged stilts. These species all breed in western continental Europe, where several of them have shown increasing populations over recent years; combined with predictions that the British climate will become increasingly suitable, this could make colonisation of Britain more likely. Another waterbird, the little egret, used to be only an occasional springtime visitor to Britain but from the late 1980s, the frequency and duration of visits increased, leading to confirmed breeding by 1996. It is now well-established. Little egrets are sensitive to periods of cold weather, so climate change appears to be linked to the species’ establishment.

Not only birds are moving: there are several examples of colonists from other groups. The small red-eyed damselfly has spread north through Europe since the 1980s, and was found on the east coast of England in 1999, thereafter spreading further; this colonisation is believed to be linked to the warming climate. The wasp spider, which was first observed on the south coast of England in 1922, has spread throughout south-east England; its northward spread in Europe may be associated both with a warming climate and recent adaptations that allow the species to tolerate slightly cooler climates. Climate change might also have played a role in Nathusius’ pipistrelle bats starting to breed in the UK in the 1990s.

Successful colonists appear, typically, to be more mobile species: if species are more mobile, they will be better able to track the changing climate. However, this reinforces two issues. First, even mobile species need sufficient, suitable habitat in the new territories. For example, waterbird colonisations of the UK would be facilitated by wetland protection and the re-creation of large wetlands.
Second, less mobile species may not be able to naturally colonise new territories. It has therefore been argued that conservationists could help these species to establish populations in newly suitable areas — so-called “assisted colonisation”. This has been shown to be feasible for marbled white and small skipper butterflies within the UK, and has been suggested for the critically endangered Iberian lynx within Spain. However, moving species between countries could be associated with substantial and unpredictable impacts, so other conservation measures may provide safer options. The potential risks and benefits of assisted colonisation, and its potential applications, are therefore important parts of the debate around conservation under climate change.

The wildlife we typically accept as being part of our “native” flora and fauna is moving, and new species are arriving as colonists, partly driven by climate change. The assemblage of species we consider “native” is therefore in a state of flux. We cannot arrest the changes, so to aid adaptation it will be important to enable species to colonise new areas via provision of sufficient, suitably-protected habitat, in areas that will become more climatically suitable over time (see sections on Protected areas, from page 28; and Creating new sites, from page 35).

Case study: breeding birds colonise the UK via protected areas (Hiley et al., 2013)

Between 1960 and 2013, 20 waterbird species bred in the UK for the first time. Of these, six species established regular breeding populations: little egret, common crane, whooper swan, Cetti’s warbler, goldeneye and Mediterranean gull. Several of these colonisations appear to be associated with the warming climate.

To understand how these species colonised the UK, the location of breeding records was studied for the six colonists that now breed regularly. For all six, the first breeding records were in protected areas – British Sites of Special Scientific Interest (SSSIs) and Northern Irish Areas of Special Scientific Interest (ASSIs). For all except goldeneye, subsequent breeding records increasingly occurred outside of protected areas as populations grew: the species spread into the wider landscape. Therefore, protected areas appear to have aided successful natural colonisations of waterbirds in the UK.
The proportion of colonists' breeding pairs (little egrets) or singing males (Cetti's warblers) in protected areas (dots), and total population size (lines). For both species, the proportion of breeding records in protected areas decreased as the population grew: the species used protected areas as a platform for colonisation, before spreading into the wider landscape.

Adapted from Hiley et al. (2013), Proceedings of the Royal Society B 280 (1760), 20122310.
4) Changing populations and communities

*Changes to the species present in an area, and the abundances of these species, show that climate change is already affecting ecological communities.*

As the climate warms, the species present in a given area, and their respective abundances, are changing. New species are arriving, whilst others are disappearing; some populations are increasing, whilst others are declining. These changes do not occur uniformly across species: mobile species, those that can use a wider range of habitats, and those adapted to warmer conditions can respond better than others.

Together, this means that ecological communities – the combination of species present in a given area at a given time – are changing. This is important, as community composition influences how an ecosystem functions. However, community composition data also provide useful information on climate change impacts. The population monitoring of different groups can give an impression of the overall impacts of climate change, whilst indicator statistics can be calculated to show the changing balance of warm-adapted and cold-adapted species.

*Large-scale surveys and long-term monitoring programmes give widespread evidence of community changes in line with those expected under climate change.* Data from the UK’s Environmental Change Network (ECN) show that at northern and upland sites, between 1993 and 2007, butterflies and moths typically found in the south increased in abundance, whilst ground beetles typically found in the north declined. In the plant communities of Scottish alpine habitats – those found above the tree line on mountains – specialist alpine and northern species declined in abundance between 1963–87 and 2004–06, whilst generalist lowland species increased. Whilst some of these changes to Scottish alpine plants could be linked to nitrogen pollution, many align with expectations of climate change impacts.

British breeding birds show similar patterns. Between 1994 and 2006, the abundance and distribution of generalist species increased as temperatures rose, whilst those of specialist species declined, creating more homogeneous communities. Even communities of relatively immobile groups have shown changes: in the Netherlands, between 1979 and 2001, southerly or warm-adapted lichen species increased in abundance whilst northerly or cold-adapted species decreased.

*Changes have also been observed in marine communities.* The plankton community of the North Sea changed substantially in the 1980s, linked with a strong increase in water temperature: abundances of cool-adapted plankton species declined, abundances of warm-adapted plankton species increased, and overall species diversity increased. The plankton community changes (and associated changes to fish populations) were so large that the period of change has been termed a “regime shift.”

Information about species composition and abundances can be used to calculate metrics, known as “indicators”, that tell us more about how climate change is affecting communities. The Community Temperature Index (CTI) combines data on species composition, population abundance, and the average...
temperature with which species are associated\textsuperscript{53}. The CTI has been calculated for breeding bird communities in France\textsuperscript{53} and Sweden\textsuperscript{54}, plant, butterfly and bird communities in Switzerland\textsuperscript{55}, and for the breeding bird and butterfly communities across the whole of Europe\textsuperscript{56}. In all cases, the CTI increased between the late 20th century and the 2000s, showing that community composition shifted towards warm-adapted species. This could be caused by abundances of warm-adapted species increasing, abundances of cold-adapted species decreasing, new warm-adapted species arriving, or cold-adapted species becoming locally extinct. However, in most cases the temperature shifted more than community composition: communities are lagging behind climate change\textsuperscript{53, 54, 56}.

\textbf{Case study: a climate change indictor for birds in Europe (Gregory \textit{et al}, 2009)}\textsuperscript{57}

The Climatic Impacts Indicator (CII) indicates the overall impact of climate change on the European bird community, by examining the changing abundances of those species predicted to benefit from climate change, and those predicted to be adversely affected. To construct the indicator, Gregory \textit{et al} modelled the impact of future climate change on European bird species’ distributions. Species predicted to increase their range (30 species, including bee-eater, hoopoe and Cetti’s warbler) were grouped together, as were species predicted to experience range decreases (92 species, including lapwing, wood warbler and willow tit).

They then examined how the different groups actually fared over recent years, using data from large-scale bird surveys across Europe. These indices reflect observed population trends and the climatic sensitivity of the species: higher values mean the species were doing better; lower values mean the species were doing worse.

Birds predicted to do well under climate change, often species associated with warmer conditions, declined between 1980 and 1990, but since then have shown a big increase. Species predicted to do poorly under climate change, often those associated with cooler conditions, declined from 1980 onwards. \textbf{Overall, this shows that European bird populations appear to be responding to climate change, with warm-adapted species increasing in abundance and cool-adapted species decreasing.}
Weighted population trends of European birds expected to benefit from climate change (red line) and those expected to be adversely affected by climatic change (blue line). Species population trends were weighted by modelled climatic sensitivity. Until 1990, both groups show declining populations. After 1990, the trends diverge: species predicted to benefit show strong population increases, whilst species predicted to suffer continue to decline.

Figure produced following the methods of Gregory et al. (2009), PLoS ONE 4(3), e4678: RSPB/EBCC/University of Durham/University of Cambridge.
The final CII was constructed by comparing the two population trends. Simply, the more the trends diverge, the more the CII rises, giving a measure of the total impact of climate change on European bird populations. Between 1980 and 1990, there was a slight decrease in the CII, coinciding with a period of colder winters and with land-use changes. However, from 1990 onwards, the CII showed a strong increase, coinciding with strong temperature rises: climate change is already having an impact on bird communities across Europe, and the impacts are becoming stronger.

The final CII indicator, showing the overall impact of climate change on European bird populations. After an initial slight decrease through the 1980s, the CII increases strongly through the 1990s and 2000s: the impact of climate change on European bird populations is increasing.

Figure produced following the methods of Gregory et al. (2009), PLoS ONE 4(3), e4678: RSPB/EBCC/University of Durham/University of Cambridge.
5) Changing interactions between species

Some of the strongest impacts of climate change on wildlife come from changes in interactions between species, in particular the relationships between predators and prey.

An ecological community comprises a number of different species interacting with each other: predators and prey, herbivores and food plants, parasites and hosts. As shown in the previous section, climate change is altering the make-up of ecological communities. This can dramatically affect the nature and dynamics of interactions between the species within communities. Indeed, a recent review suggested that changed interactions among species could be the single most important mechanism behind climate change impacts on wildlife, particularly for predatory species, and is potentially the biggest driver of local extinctions. Understanding changing species interactions could therefore be vital for understanding climate change threats to wildlife.

One important way in which the dynamics of ecological communities is changing is via shifts in the timing, or phenology, of seasonal events. This is particularly notable in spring, when temperature dependent events, such as commencing breeding, eggs hatching or tree buds opening, are occurring earlier. Across 726 UK species, covering marine, freshwater and terrestrial environments, spring and summer events occurred 3.9 days earlier per decade on average between 1976 – 2005. However, not all species responded in the same way: primary producers (plants and plankton) and primary consumers (herbivores) responded faster than secondary consumers (predators). This “phenological mismatch” could disrupt interactions between species within the food web, resulting in food being available at the wrong time.

Some of the best examples of phenological mismatch come from woodland food chains in the Netherlands. Between 1988 and 2005, oak leaves emerged 1.7 days earlier per decade, caterpillar abundance peaked 7.5 days earlier per decade, egg hatching of great tits, blue tits, coal tits and pied flycatchers became 3.6–5.0 days earlier, while egg hatching of sparrowhawks did not advance. Hence, over the course of the study, the matching between different levels of the food web became poorer. Pied flycatcher populations declined most strongly in those areas where the mismatch between the caterpillar peak and timing of breeding was greatest, suggesting that earlier caterpillar emergence was detrimental to the birds. For great tits, the number of chicks fledged and fledgling weight was influenced by how well egg laying matched the caterpillar peak.

Phenological mismatch is also a risk in marine environments. In the North Sea, different groups, from plankton, through fish, up to seabirds, are shifting timings at different rates. When North Sea plankton groups were studied between 1958 and 2002, diatoms, a group of algae, did not bloom any earlier, but plankton species higher up the food chain, including fish larvae, peaked substantially earlier, possibly reducing efficiency of energy transfer through the food chain.
However, phenological mismatch may not have severe consequences in all habitats and for all species. For the marbled white butterfly in the UK, impacts of timing mismatches with its main nectar source, greater knapweed, might be minimised by using plants in different microhabitats – such as warmer south-facing slopes and cooler north-facing slopes – that produce variety in the plant’s flowering time. In Dutch long-distance migratory birds, although forest-dwelling species declined strongly between 1984 and 2005, marsh-dwelling species did not; this is possibly because forests are highly seasonal systems with short food peaks, raising the risk of phenological mismatch, whereas marshes are less seasonal.

In the British uplands, phenological mismatch between golden plover egg laying and emergence of their cranefly prey appears to be less important than cranefly abundance (itself influenced by climate) in influencing plover populations.

Evidence of impacts on predator-prey relationships from a range of systems suggests that changing prey availability or quality, or abundances of predators, could have substantial impacts on wildlife. In the Czech Republic, higher temperatures have allowed populations of the edible dormouse to increase, leading to increased nest predation on great tits and collared flycatchers. In Norway, willow grouse chick production is lower in years following hot Augusts: after hot summers, bilberry plants provide lower-quality food for the grouse, and moths that are important prey for grouse chicks are less abundant. In Welsh upland streams, high temperatures in two years in the early 1990s were associated with very low abundances of freshwater invertebrates such as caddisfly larvae, in turn leading to local extinction of one of their predators, a flatworm species associated with cooler habitats.

As seems to be the case with phenological change, the risk is magnified up the food chain. In German grasslands, more than twenty years of data on plants and insects showed that community composition of producers (the plants) was less sensitive to climate change than was that of herbivores (some grasshoppers, true bugs), which in turn was less sensitive than that of carnivores (beetles, spiders).

Case study: food web disruption and North Sea kittiwakes (Carroll et al, 2015)

The UK black-legged kittiwake population has declined by around 70% since 1986. Both breeding success (the number of chicks fledged) and adult survival rates are falling. Work on the Isle of May population in Scotland indicates that breeding success and survival could be affected by two key things. First, North Sea kittiwakes rely heavily on sandeels for food during the breeding season, so sandeel fisheries could remove vital prey. Second, when the sea was warmer, survival and breeding success were lower. So, human activity and changing ocean conditions – driven by a warming climate – could be acting together to threaten kittiwakes. However, it is likely that the impacts of rising temperatures are not direct, instead reflecting shifts in the food web.

Rising temperatures have been associated with a dramatic change in the North Sea plankton community, as cool-adapted plankton species are replaced by those adapted to warmer waters, but which seem less able to support the sandeels that feed on them. However, temperature is not the only important environmental factor. In the spring, changes to seawater temperature and salinity lead to sharp density differences between deeper and shallower waters – this is called stratification. Earlier stratification could
cause a mismatch between plankton availability, sandeel development, and kittiwake food requirements\textsuperscript{75}, while stronger stratification can favour less nutritious plankton species and make the seabed less suitable for sandeels\textsuperscript{76, 77}. Driven by rising temperatures and changes to stratification conditions, changed species interactions could combine to reduce food availability for kittiwakes\textsuperscript{78, 79}.

Recently, large-scale tracking studies using lightweight GPS tags have yielded unprecedented amounts of information about where kittiwakes feed during the breeding season. Tracking data from 11 colonies (from northern Scotland, to eastern England and Wales) were used to model the effects of changing sea conditions in feeding areas on kittiwaKe breeding success.

Foraging areas of kittiwakes (coloured patches), identified by attaching lightweight GPS tags to a number of birds at eleven colonies (white diamonds) during the breeding season. The foraging area of each colony is identified with a different colour. Data on ocean conditions were extracted for these areas, to see how ocean conditions in feeding areas affected breeding success.

Figure reproduced courtesy of Matthew Carroll.
Results indicated that higher sea temperatures led to lower kittiwake breeding success, supporting previous findings that warming seas are a threat. Further to this, earlier, stronger ocean stratification did indeed reduce breeding success, confirming suggestions that climate change could affect kittiwakes via more than temperatures alone. Based on these relationships, projections for the late 21st century suggested that the breeding success of the eleven colonies could fall by 21–43%.

Modelled kittiwake breeding success for the eleven colonies for a 20th century “baseline” and the late 21st century. Driven by warming seas and stronger, earlier stratification, the model suggested that kittiwake breeding success could fall 21–43%.

Adapted from Carroll et al. (2015), Climate Research 66, 75–89.
6) Extreme weather

*Increases in the frequency and intensity of extreme weather events can be expected to have an increasing impact on wildlife populations.*

Wildlife already deals with a variable climate, but since 1950 there have been increases in the length and frequency of heatwaves, the frequency and intensity of heavy rainfall events, and the frequency and intensity of droughts in some areas. Since 2000, numerous weather events have broken records, with, for instance, the hottest European summer in 500 years occurring in 2003, thus appearing to show that the climate is becoming more extreme. IPCC (The Intergovernmental Panel on Climate Change) projections show that, in the future, the frequency and intensity of such events will increase, potentially representing a major source of impacts on wildlife.

From the perspective of wildlife impacts, extreme weather means events of large magnitude and low frequency relative to the lifespan of the animals or plants being considered. As these are infrequent events, to see how wildlife populations could react to increasingly extreme weather, we can examine how they already respond to severe weather events and climatic variability.

One of the most obvious impacts of severe weather on wildlife is high mortality. Because their plumage is not fully waterproof, shags in Scotland survive less well in years with strong onshore winds and high rainfall in February, sometimes leading to mass mortality events known as “wrecks”. Projections show that more variable weather could lead to increased risk of extinction for shag populations. Temperature extremes can also affect survival. Swiss barn owls monitored between 1934 and 2002 had lower survival rates in winters when snow-cover lasted longer. Conversely, lambs of mouflon (wild sheep) in southern France survived much less well during the severe summer drought of 2003 (caused by the hottest summer in over 500 years), probably because of food shortages.

Extreme weather can also affect reproductive success. Slavonian grebes in Scotland had higher breeding success when temperatures during chick rearing were higher, this relationship being driven primarily by poor chick production if there were very cold spells during breeding. Slavonian grebe populations were also sensitive to rainfall, with heavy rain during the breeding season leading to smaller populations. In the Netherlands, oystercatcher chick fledging success was always low in years with high summer flood risk. This could be increasingly problematic, as floods increased in frequency and intensity from 1971–2008 and may increase further as sea levels rise. Plants also suffer impacts of severe weather on reproduction: in the Apennines in Italy, foxtail grass and a vetch species produced fewer flowering stems and fewer flowers per stem in the 2003 summer heat wave.

The ability of animals and plants to cope with extreme weather impacts varies within and between species, and can be influenced by the way humans manage the landscape. In the 2003 heat wave, French bird species with a wider temperature tolerance (the difference between the hottest and coldest temperatures found in the species’ European range) were most resilient to the extremely high
temperatures. Following a severe drought in the UK in 1995, ringlet butterfly populations crashed; those in drier areas experienced the biggest crashes, whilst those in areas with more woodland, and less fragmented woodland, declined less and recovered faster. Similarly, following a severe drought in autumn 2002, common frogs in Finnish farmland showed much reduced egg production and strong population declines, but populations were more resilient in landscapes with more varied habitats. Finally, in an extreme drought in Sweden in 1992, bush cricket populations were more resilient in tall rather than short grassland, likely due to increased humidity in taller vegetation. Further, the crickets moved into forests during the drought; this habitat would usually be avoided, but was presumably favoured during the drought due to increased humidity. These examples show that it is important to consider how sensitive species are to extreme weather, and how habitats and landscapes can be managed to improve population resilience (see section on “Managing sites”, from page 31).

Case study: impacts of extreme rain and floods on UK birds

Capercaillie breeding success and rainfall (Summers et al, 2004; Summers et al, 2010)

The capercaillie is a large woodland grouse that is an iconic species of Scottish native pine forests. However, its population has declined rapidly since the 1970s, linked to low breeding success and collision mortality in adult birds. The capercaillie population in Abernethy Forest was studied from 1989–99 to examine why the species suffers from low breeding success. Over this period, in years with heavy rainfall, productivity was very low: when June rainfall exceeded 80–100 mm, virtually no chicks were raised. Breeding success was also affected by predation, but rainfall was the overriding factor: breeding success was low in wet years, even when predation was low.

High June rainfall causes high chick mortality, likely due to reduced food supplies and increased chilling of chicks. It was thought possible to mitigate some of the impacts of high June rainfall with vegetation management, but trials involving cutting pathways through tall heather failed to increase breeding success, even with a predator control programme in place. Historical weather data show that very wet Junes have increased in frequency, so in the longer term, this could have an increasing impact on capercaillie breeding success: even if Highland summers become drier overall, increasingly intense June rainfall events could still be detrimental to the capercaillie.

Bearded tit survival and flooding (Wilson & Peach, 2006)

With a distribution restricted to reedbeds, the bearded tit is a species of conservation concern in the UK. At one breeding site, Leighton Moss in north-west England, the adult population increased from 60 to 180 between 1992 and 2000. However, in October to December 2000, exceptionally high rainfall occurred in England – the highest total for over 300 years – leading to a severe winter flood and a bearded tit population crash of 94%. Survival was very low, with the flood appearing to be the main cause. The flood prevented the birds foraging in the layer of reed litter in the reed bed, severely reducing food availability. Adults weighed in December 2000 were 20% lighter than in preceding years. As climate change projections suggest that autumn and winter rainfall could increase over time, the risk posed by extreme floods to bearded tit populations could increase in the future.
Estimates of bearded tit survival and population size at Leighton Moss. Bars show the number of adults, circles and the solid red line show adult survival, and diamonds and the dashed dark blue line show survival of birds in their first winter. Extreme rainfall and a resulting flood between the 2000 and 2001 surveys led to much-reduced survival and a 94% population crash. After this, survival increased again, but population levels recovered slowly.

Adapted from Wilson & Peach (2006), Animal Conservation 9 (4), 463–473.
7) The future

Further, large shifts could occur in species’ ranges in the future, with many species losing large areas of suitable climate, creating a substantial threat to their survival.

Examples so far have shown that species distributions, species interactions, reproduction and survival have already been affected by the changing climate. IPCC projections show that by the end of the 21st century, global temperatures are likely to have increased by at least 0.9°C and as much as 5.4°C, relative to 1850–1900. The impacts on wildlife are therefore likely to become more severe, so it is important to use our understanding of ecology to examine what might happen in the future.

Much work to understand future impacts of climate change on wildlife involves the use of species distribution models, which establish statistical relationships between species’ current distributions and important climate variables, including moisture availability, minimum temperatures and summer warmth. Once these associations are established, projections of future climatic conditions can be used to see where might be suitable for a species in future. Understanding how these potential distributions change in location and size is vital to understand and prepare for longer-term impacts of climate change on wildlife.

The future potential geographic ranges of a wide range of species are projected to shrink and shift northwards under climate change. For some groups of animals, assessments of future potential ranges have been made for all species in Europe. Many European butterfly species are projected to shift north over the 21st century and the climatically-suitable area will decrease for many. If populations can’t disperse well, and under a high climate change scenario, nearly a quarter of butterfly species could lose over 95% of their current range by 2080, and nearly four-fifths would lose over 50%. Even if climate change proceeds at an intermediate rate, nearly a tenth of species would lose over 95% of their current range, and two-thirds would lose more than 50%. Similarly, for European bumblebees, around a third of species could lose over 80% of their current range by 2100 under a severe climate change scenario, whilst around two-fifths of species could lose over 50%.

The greater the loss of suitable climate, the greater the threat to the species’ survival. Projections have also been made for a variety of other groups. One study modelled the distributions of 1,350 European plant species – just over 10% of all plant species in Europe. Assuming a high rate of climate change and no migration of species, over a fifth of plant species modelled could lose over 80% of their range by 2080, and 2% could go extinct altogether; even allowing for migration and with limited climate change, many species face losing large proportions of their current ranges. Among 1,648 European freshwater species, including plants, fishes, molluscs and amphibians, many were projected to shift north-east by the 2050s under an intermediate climate change scenario; nearly three-fifths of the species were projected to lose over 50% of their current range; rare species were most threatened, with nearly four-fifths losing more than 90% of their current range. For fish populations in the North Atlantic, rising sea temperatures were projected to drive substantial distribution changes in a range of fish species by the 2090s: southerly-distributed species such as anchovy and horse mackerel were projected to occur
Throughout the North Sea, whilst northerly-distributed species like haddock and saithe were projected to be lost from the southern North Sea\textsuperscript{100}.

**Although many models consider how distributions might change, conservationists also need to consider population abundances.** In a model of British breeding birds, populations of two northerly-distributed British breeding bird species, the Eurasian curlew and meadow pipit, were projected to decline over the 21st century, with the curlew decline particularly sharp\textsuperscript{101}. Conversely, the same study suggested that two southerly-distributed species, the Eurasian nuthatch and green woodpecker, could increase substantially in both abundance and range\textsuperscript{101}.

**Habitat availability is another key influence on future distributions and conservation strategies.** Modelling studies of the Austrian Alps suggest that, even with only 1.8°C warming, many plant and invertebrate species found only there — endemic species — could lose their mountain-top habitat as the tree line moves uphill in response to warming\textsuperscript{102}. Large European mammals are also projected to be threatened, with changing land use interacting with the changing climate to drive substantial habitat loss: on average, 10–25% of habitat could be lost by 2050, with high-latitude or high-altitude species such as reindeer and chamois likely to fare particularly badly\textsuperscript{103}.

**It is also important to consider how populations might behave and species interact in landscapes changed by climate change.** A model of Iberian lynx populations combined projections of climatic suitability with population models of both the lynx and of rabbits, the lynx's primary prey. Results indicated that, without significant conservation interventions, climate change could drive the Iberian lynx to extinction by 2050\textsuperscript{45}.

Ecological modelling can use relationships from the present to make valuable projections of the future. It is important to note that projections are not firm forecasts or predictions: they show what might happen based on a set of possible conditions, and there are many factors the models do not yet incorporate. However, although projections might seem detached from real impacts, populations are already showing the responses projected (see section on “Community change”, from page 13). Therefore, climate change looks set to increasingly affect wildlife populations, and whilst some species could do well in some places, many populations, and perhaps even entire species, could be at risk of extinction.

**Case study: climate change and breeding bird distributions (Huntley et al, 2007)\textsuperscript{35}**

Huntley et al developed models of the distributions of 453 European breeding bird species using information on breeding distribution between 1961–1990 and three important climate variables: one indicating the degree of winter cold, another indicating available summer warmth, and the last indicating moisture availability. These models were then combined with projections of future climatic conditions for 2070–99, to give an indication of potential future distributions.

These projections indicate the potential range: the areas where climatic suitability suggests a species could occur. However, for a species to occupy its climatically-suitable area, there must be appropriate habitat and sufficient other resources, and it must be able to disperse across the landscape. On average, by 2070–99,
species’ potential ranges were projected to be nearly 550 km further north and north-east. However, there was variation in the directions that species were projected to move in: ecological communities will change as species respond differently to the changing climate.

**Dartford warbler**

Present and future potential distribution maps for Dartford warbler, a southerly-distributed species, and willow (red) grouse, a northerly distributed species, in 1961–90 and the late 21st century. Blue squares show where climate is suitable for the species to occur; yellow squares show where the species are predicted to be absent. For both species, the area with suitable climate will decrease, and will show limited overlap with the existing range. For Dartford warbler, Britain could become more important under climate change; for willow grouse, much of the existing British range could become unsuitable.

Under all climate change scenarios, future breeding distributions were only around 80% of the size of current distributions. These shifting, shrinking distributions led to limited overlap (40% on average) with recent distributions – 27 species had no overlap between recent and future distributions, while 51 species had less than 10% overlap. The smaller the overlap, the greater the extinction risk. Endemic species – those found only in Europe – appeared to be at greater risk, with an average overlap of only around 15%. Overall, the changes to the European bird community could be substantial.

These shifting distributions could lead to more species in some areas, and fewer in others. The UK could become important for some species currently found further south, reinforcing the need for regional co-operation in adaptation, but species currently found in the north and uplands could face substantial loss of suitable locations.
8) Protected areas and climate change

As species’ ranges shift, both existing and new protected areas will play an important role in helping wildlife cope with the effects of climate change.

Protected areas are crucial in conservation. In the much-altered landscapes of Europe, they provide plants and animals with the conditions and habitat they need to survive. They are not solely nature reserves, but represent “a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values”\textsuperscript{104}. Around 21% of EU land or water is protected in some way, covering around 1,200,000 km\textsuperscript{2}\textsuperscript{104}. It is important to examine the role protected areas will play in a world increasingly affected by climate change.

Empirical evidence shows that protected areas are already proving important as the climate changes. Protected areas can aid threatened wildlife by allowing larger, more resilient populations to become established. Across 415 European breeding bird species, long-term (1980–2012) population trends were in the direction expected under climate change, confirming that climate change is already influencing the species\textsuperscript{105}. However, those species protected under Annex I of the EU Birds Directive, of which a key element is the establishment of Special Protection Areas (SPAs) for important habitats and populations, had more positive population trends. Provision of protected areas, along with other protection measures, aids populations despite the underlying effects of climate change\textsuperscript{105}.

Similarly, across 90 bird species in Finland, between the 1970s and 2000s, some communities showed declining diversity and others showed increasing diversity (both in line with predictions of climate change impacts)\textsuperscript{106}. However, regardless of the trend, protected areas maintained higher numbers of species than unprotected areas\textsuperscript{106}.

As well as helping species to establish larger, more resilient populations within their existing range, protected areas also help species colonise and establish in new areas, even though the protected areas there were not designated for those species. The silver-spotted skipper butterfly has expanded its UK range in recent years: protected areas actively managed for conservation were over three times more likely to have been colonised than unmanaged protected sites or unprotected sites, and population survival was higher in protected sites\textsuperscript{107}. Of 57 butterfly species and 42 dragonfly and damselfly species in the UK, 61 species were more abundant inside protected areas than outside, when looking at areas colonised since the 1960s–80s: protected areas appear to have helped species to establish larger populations during range expansion\textsuperscript{108}. Likewise, in Europe, as the wintering smew distribution has shifted north-east, population growth in the north-east has been nearly twice as fast inside SPAs than it has been outside\textsuperscript{109}.

But what about the future? A modelling analysis, looking at plants, mammals, birds, amphibians and reptiles, considered the importance of protected areas across Europe: climatic suitability in protected areas was projected to decrease by 2080 for 58–63% of species modelled, based on their current distributions (ie, assuming species cannot move in response to climate change)\textsuperscript{110}. Although some species could see
climatic conditions improving, a greater proportion of the species modelled would see climatic conditions deteriorating (ie “losers” were projected to outnumber “winners” across most groups)\textsuperscript{110}. However, for most groups, protected areas would retain suitable climate as well as, or even better than, areas outside of the network\textsuperscript{110}. More northerly areas, such as parts of the UK and Scandinavia, and higher-elevation areas, such as the Alps, were projected to have more “winner” species, whilst more southerly countries were projected to have more “loser” species\textsuperscript{110}.

However, even with some reductions in climate suitability, protected area networks should continue to function effectively. A study of SPAs in the UK found that although climate change could cause the abundance of breeding seabirds and wintering waterbirds to decline over the next 70 years, most SPAs would keep large enough populations of their key species to warrant continued legal protection\textsuperscript{111}. Further, although some SPAs may lose some qualifying species, new species are expected to arrive: sites that are currently important should remain important and the site network as a whole should remain resilient\textsuperscript{111}.

A similar modelling exercise considered how four bird of prey species would be protected by Natura 2000 sites under future conditions: although some sites could become less important, the network as a whole should maintain current performance\textsuperscript{112}. Increasing connectivity between southern and northern protected sites would benefit lesser spotted eagles, whilst adaptation for griffon vultures, golden eagles and Egyptian vultures can be achieved by maintaining and expanding existing protected areas\textsuperscript{112}. Finally, 2,500 plant species in the French Alps were modelled, and the effectiveness of existing protected areas was assessed: by 2080, although plant communities could experience substantial changes, the protected area network would remain effective, with rare species experiencing smaller impacts, and threatened species protected just as well in the future as the present\textsuperscript{113}.

It is clear, however, that additional conservation efforts will be needed to supplement the existing protected area network. A study of 1,200 European plant species generated a theoretical reserve network based on current distributions of species; future distributions under climate change were then projected, and the effectiveness of the simulated reserve network assessed\textsuperscript{114}. Depending on assumptions used, 6–11\% of species lost suitable climatic conditions from the “current” reserve network\textsuperscript{114}. Another analysis considered plant species in protected areas in Western Europe: under future climates, the current protected area network could need to expand by 30–40\%\textsuperscript{115}. Given that further protected areas are likely to be required, it will be important to identify areas that would be important under both current and future climates\textsuperscript{115} (see section on “Creating new sites”, from page 35). In some cases, other conservation measures such as translocation (or even assisted colonisation outside the current range) might need to be considered\textsuperscript{114}. 

29
Case study: protected areas, survival and colonisation

Protected areas and shifting range margins (Gillingham et al, 2015)\textsuperscript{116}

The role of protected areas at expanding northern range margins and retracting southern range margins has been examined for seven butterfly species and eleven bird species in Britain. Some are found in southern Britain, so might spread north into new areas, and some are found in northern Britain, so might lose the southernmost parts of their range. Distributions were compared between an early time period (ranging from the 1970s to the 1990s, dependent upon data availability) and a later time period (ranging from the 1990s to the 2000s). Protected areas were defined as sites with Site of Special Scientific Interest (SSSI) designation.

Among the northern species considered, survival at lower latitudes and altitudes was more likely in areas with a higher coverage of SSSIs – species were more likely to persist at their southern range margin in areas with greater protection. Among the southern species considered, colonisation was more likely in areas with higher coverage of SSSIs – as their range expanded, species were more likely to colonise areas with greater protection. Overall, therefore, protected areas appeared to facilitate both population persistence and colonisation as species’ ranges shifted.

Protected areas and range expansions (Thomas et al, 2012)\textsuperscript{117}

Seven British species – two butterflies and five birds – were examined in detail to see whether their northwards range expansion was influenced by protected areas. Species distributions were compared between the 1970s–80s and the 2000s, to identify sites that had been colonised. Protected areas were colonised 4.2 times more frequently than expected given the available coverage of protected areas. Across 256 invertebrate species with less detailed survey data, 251 were recorded more frequently than expected in protected areas in newly-colonised parts of their ranges. This suggests that protected areas are already facilitating range expansions in response to the warming climate.

Map of Dartford warbler breeding distribution (left figure), showing sites where breeding commenced before 1991 (blue squares) and where breeding commenced after 1991 (red squares). Expanded view of the black box (right figure) shows SSSI coverage in green, and locations where Dartford warblers were observed: sites colonised after 1991 (red crosses) are clustered in and around protected areas.

Reproduced with permission from Thomas et al. (2012), Proceedings of the National Academy of Sciences 109 (35), 14063–14068.
9) Managing sites and landscapes for adaptation

*Different site management techniques will become more important to help wildlife to adapt to climate change.*

The way sites are managed – both protected areas and other sites – influences the role they play in helping wildlife adapt to climate change. It is already clear that areas with active conservation management are more beneficial than those without\(^\text{107}\). However, site management can also interact with wider landscape management to influence how species respond to climate change.

Three common aims of site management for climate change adaptation include: increasing resistance to climate-driven change; helping populations to be more resilient, to bounce back from impacts of climate-driven change; and accommodating climate-driven change\(^\text{118}\). Much site management for adaptation targets the first two aims: counteracting climate change effects with action to reduce the severity of the impacts, and tackling non-climatic stressors to compensate for climate change effects\(^\text{119, 120}\).

*A key action is to provide a range of microhabitats and microclimates – small-scale patches where habitat or climate differ from prevailing local conditions.* Increased variation creates a range of options for species that might need to adapt. For Glanville fritillary butterflies in the UK, egg-laying occurs on plants that are warmer than the ambient air temperature, and abundances are higher where the habitat contains bare ground and short grass\(^\text{121}\). Creating a mosaic of short turf and taller vegetation would provide variation in thermal conditions, allowing flexibility in egg-laying locations to counteract variable temperatures under climate change\(^\text{121}\). In European deciduous forests, managing forest canopies to retain denser cover could help cool-adapted plants on the forest floor, with cooler microclimates limiting some of the effects of climate change\(^\text{122}\).

Such thinking is already being put into practice. At the Winterbourne Downs RSPB nature reserve, a lowland grassland site in southern England, S-shaped chalk banks have been created and planted with butterfly food plants. This creates a range of different microclimates, providing warmer and cooler areas so that insects can find suitable conditions under a range of climatic conditions.

*Hydrological management is also often important.* Shallow drainage channels on farmland, which can produce small surface floods, are associated with greater abundances of breeding lapwings, and more nests nearby\(^\text{123}\). With climate change expected to increase risk of both flooding and droughts, these shallow drains could help retain water throughout the breeding season and prevent larger floods following heavy rain\(^\text{123}\).

Black-tailed godwits in the UK nest in wet meadows used for floodwater storage; so have much reduced breeding success during floods\(^\text{124}\). Increased flood risk under climate change could threaten the populations, so flood mitigation measures in the meadows and provision of better habitat in adjacent farmland is needed to safeguard the population\(^\text{124}\).
The area and quality of habitat patches, along with characteristics of the wider landscape, are key considerations. The silver-spotted skipper butterfly is expanding its range in the UK; between 2000 and 2009, higher survival in colonising populations was associated with larger habitat patches, increased availability of sheep’s fescue grass, and intermediate bare ground cover. Providing such habitat features is important to aid expansion of the species’ range. Similarly, woodland specialist bird species in the UK, such as nuthatch and green woodpecker, recovered better from small population sizes when in larger woodlands. Landscape characteristics can also influence the extent of climate impacts: generalist woodland species are less sensitive to very cold winters in landscapes with less fragmented woodland cover.

Climate change could also interact with changing management of the wider landscape. In the Netherlands, the black-tailed godwit population has declined: this appears to be linked to a combination of land management and climate change, with rising temperatures and agricultural intensification combining to reduce the amount and quality of the habitats that chicks need for foraging. Agri-environment schemes could help to address some of the issues, but need to be designed and implemented to take into account the effects of both agricultural impacts and rising temperatures.

In the French Alps, a modelling study considered how pasture management and climate change could interact in the future: intensification of pasture use would cause rapid loss of plant diversity, with climate change gradually leading to further losses; abandonment of pasture could initially increase diversity, but climate change could then decrease diversity further as the tree line rapidly expands. Maintaining low intensity pasture may therefore be the best option under climate change.

Another modelling study considered the effects of landscape management on breeding wading birds in the Netherlands: conversion of pasture land to bioenergy crops, which could be an element of human climate change adaptation, would reduce habitat suitability for the birds by reducing habitat openness and raising groundwater levels. Climate change will influence the way humans manage land, and these changes will be an important determinant of how wildlife adapts to climate change.

Protected areas may be specifically managed for conservation purposes; evaluating and altering this management is an important part of improving the resilience of wildlife populations under climate change, helping species move through the landscape effectively, and ameliorating negative impacts. However, large areas of Europe are under intensive agricultural or forestry management. The management of this wider landscape must therefore also be considered, with larger-scale management changes such as land abandonment or shifts to new crops potentially affecting species’ responses to climate change.
Case study: climate change resilience in upland birds (Carroll et al, 2011; Carroll et al, 2015)\textsuperscript{130,131}

The European golden plover breeds in the UK uplands, but these breeding populations are among the most southerly in its range, potentially making them susceptible to climate change impacts. During the breeding season, golden plovers rely on craneflies for food, but cranefly larvae are sensitive to drought, meaning that climate change could threaten the birds’ food supply\textsuperscript{132}. Modelling suggests that the abundance and persistence of golden plover populations in the Peak District of northern England could decline as warmer, drier summers reduce cranefly abundances.

However, management could increase resilience of these populations. Throughout the 20th century, many British upland peatlands were drained with the intention of improving agriculture, but drainage could exacerbate cranefly declines and have further impacts on ecosystem functioning. Experimental examination of three drained peatlands has shown that blocking drains as part of restoration programmes leads to wetter peat and higher cranefly abundances.

Modelled golden plover abundances in the Peak District under recent conditions and for a future climate change scenario: darker red indicates higher abundances, greys and lighter reds indicate lower abundances. Abundances are projected to decline overall and populations to retract into the wettest areas where cranefly abundances remain high.

Reproduced with permission from Carroll et al. (2015), Nature Communications 6, 7851.
Cranefly abundance at drains that have been blocked during restoration and those that remain open. Higher abundances were found at blocked drains. Sampling occurred immediately at the drain edge (near) and 10 m away (far), showing that the benefits of drain blocking extend away from the drains.

Adapted from Carroll et al. (2011), Global Change Biology 17 (9), 2991–3001.

Blocking drainage ditches could therefore provide more food for golden plovers in drained peatlands, aiding populations under climate change. Other ecosystem services benefits could also be achieved by drain blocking, such as improved carbon storage, improved water quality and reduced flood risk (eg Wilson et al, 2011)\textsuperscript{133}.

Blanket bog restoration and drain blocking have already been carried out by the RSPB and partners in projects such as the Sustainable Catchment Management Programme (SCaMP) in the Peak District and the Active Blanket Bog Wales EU LIFE project. These projects show how, by acting on site management now, we can provide immediate benefits as well as longer-term climate change resilience.
10) Creating new sites and expanding site networks

Creating, re-creating and protecting new sites for wildlife conservation will play important roles, from helping populations to disperse through inhospitable landscapes, to increasing the size of existing protected areas to enhance their resilience, to providing entirely new locations for populations to inhabit.

Creating new areas of habitat and new protected areas may be necessary to compensate for areas where existing habitat is under threat, in areas that are likely to become more important under climate change, and where populations need to move across the landscape to track suitable climate. It is therefore important to consider how the creation of new sites could aid wildlife.

One key adaptation action is to increase the ability of populations to track suitable climate. Habitat fragmentation, where formerly continuous areas of habitat are broken up into smaller, unconnected pieces, could worsen the impacts of climate change by limiting species’ ability to colonise newly-suitable areas. However, many habitats are already fragmented, and protected areas may be surrounded by a matrix of less suitable habitat, meaning that a core function of site creation could be to improve the connectivity between areas of suitable habitat. Connectivity could be achieved by making the wider landscape more wildlife-friendly, but could also be done using “wildlife corridors”, whereby smaller areas of habitat are created to join together larger main patches. Some empirical evidence shows that species use corridors or scattered habitat patches to move across landscapes. Further, if populations in core areas decline, due to extreme weather for example, then improved connectivity might allow “rescue” of that population as individuals from nearby areas recolonise.

A model of habitat creation in Yorkshire suggested that linking existing good-quality habitat patches to prevent “bottlenecks” (where species cannot reach good quality habitat) would be the most effective way of promoting movement across the landscape. However, adding more habitat near to good-quality, well-connected patches might be better at increasing population persistence, suggesting that promoting dispersal and increasing persistence might require two complementary, but different, habitat creation strategies. On balance, larger, better quality habitats might aid wildlife populations even more than smaller, well-connected habitats.

In some instances, creating new sites for wildlife might not seek to simply link together existing areas, but to provide entirely new opportunities in areas likely to become climatically suitable. In Italy, a modelling study suggested that both nationally-designated protected areas and Natura 2000 sites are crucial to achieve good protection of amphibians under climate change. However, areas that would become more important under climate change were also discovered, suggesting that the creation of further reserves in parts of Sardinia, Sicily and the north-east mainland would enhance the network further.

Similarly, modelling of otter distributions in Europe identified areas that are likely to become more suitable under climate change, where otters don’t currently occur, such as areas of central-northern Italy, southern
France and eastern France. Habitat creation and protection could be put in place in these climatically-suitable areas to promote otter expansion under climate change.

Observations of ongoing changes can inform approaches to creating new sites. For example, the RSPB has re-created rare lowland heathland further north than the core range of many associated species, so that as the climate warms, there will be habitat available for the populations to colonise. Similarly, it has been suggested that large wetlands should be created in Britain to accommodate incoming waterbird species that require large areas of habitat to establish breeding populations: existing wetlands in Somerset, Cambridgeshire, Norfolk and Suffolk could be the focus of such habitat creation. Habitat creation can also counter some impacts of sea-level rise: managed coastal realignment has been carried out at sites such as the RSPB’s Wallasea Island reserve, to re-create important intertidal habitats such as salt marshes, thus helping to counteract the loss of intertidal habitats elsewhere through development and “coastal squeeze.”

Case study: creating wetlands for bitterns (Ausden, 2014; Gilbert et al, 2010; Wotton et al, 2009)

Bitterns became extinct as a breeding species in Britain in the 19th century following persecution and habitat loss, but re-colonised in the early 20th century and grew to a peak of 70–80 males by the 1950s. However, the population declined again as the species' freshwater reedbed habitat degraded in some areas, reaching a minimum of 11 males in 1997. The majority of these were at coastal reedbeds in Suffolk, which were vulnerable to coastal flooding. Flooding with seawater reduces bitterns' food supply, in turn affecting their breeding success and survival. Climate change-driven sea-level rise therefore threatened these populations, as saltwater incursion was expected to become more frequent; mathematical modelling suggested that the UK population would be even more vulnerable if these core sites were flooded more often.

An ambitious habitat creation initiative began to tackle this problem, underpinned by the bittern’s legal protection under the 1979 EU Birds Directive. Reedbeds were restored and new reedbeds created at sites further inland, away from areas vulnerable to coastal flooding. Population monitoring indicates that bittern populations have rapidly increased in the new reedbeds, so that as the total national population has grown, the risks posed by sea-level rise have decreased. Other species have benefited too, with the first records of breeding by purple heron and great egret, and the first regular breeding of little bittern occurring in newly created reedbeds. Creating new reedbeds therefore appears to have reduced climate change risk for bitterns, whilst providing opportunities for colonising species.
Number of male bitterns on RSPB reserves under different degrees of coastal flood risk. As the population has grown, the proportion of the population at risk from seawater flooding has reduced, as populations establish in newly created reedbeds further inland.

Figure adapted and updated from Ausden et al. (2014), Environmental Management 54, 685–698.
11) Helping people to adapt

Humans and wildlife both need to adapt to climate change. Restoring and conserving natural ecosystems could, in some cases, provide benefits to nature and humans at the same time.

Like wildlife, human society also needs to adapt to climate change. A previously-discussed example showed how land management to aid human adaptation, if not done carefully, could reduce habitat quality for breeding wading birds\(^{129}\). Whilst such conflicts are possible, they are not inevitable and adaptation for humans can even be achieved via measures that benefit ecosystems and wildlife.

"Ecosystem-based adaptation" is defined by the Convention on Biological Diversity as "the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change"\(^{143}\). Adaptation of this kind includes managing uplands, water courses and flood plains to store water and reduce flood risks, managing coasts to prevent flooding and erosion, and managing forests to stabilise land and maintain water flow\(^{144}\).

These “soft”, ecosystem-based approaches can be contrasted with “hard” approaches based on engineered solutions. Although they can be effective, “hard” approaches have drawbacks. For example, sea walls can damage or alter intertidal habitats such as salt marshes, which in turn leads to a reduction in natural flood protection, as well as biodiversity loss. In a “soft” approach, combining natural defence from more extensive intertidal habitats with smaller sea walls, flood protection can be more cost-effective, provide longer-term protection under rising sea-levels and benefit biodiversity\(^{145}\). Further, “hard” interventions often only provide the service for which they were built, and are inflexible in a world that is increasingly defined by change, whereas ecosystem-based approaches provide multiple services and are very flexible\(^{146}\).

Many examples of ecosystem-based adaptation already exist, addressing adaptation to current climatic variability, rather than long-term change\(^{147}\). They are concerned, for example, with how to manage water scarcity or flooding, or how to maintain agricultural productivity, whilst the hazards addressed include changing rainfall patterns, high temperatures and sea-level rise; encouragingly, most examples report positive outcomes\(^{147}\).

Controlling flooding is a key concern under climate change. Sustainable floodplain management can be an important way to reduce flood risks\(^{148}\). Floodplain restoration around the Skjern river in Denmark commenced in the late 1990s to counteract a range of "engineered" changes made in the 1960s, such as river straightening and meadow drainage\(^{149}\). As well as benefiting wildlife, the restoration has saved water pumping costs, reduced nutrient concentrations in the water, reduced carbon dioxide emissions, provided recreation opportunities and reduced flood risk; the benefits outweigh the costs of restoration\(^{149}\). Similarly, areas of floodplain around the lower Danube have recently been restored after agricultural conversion and dike building led to increased flood peaks: in 2005, a single flood cost €396 million in damages, and flood frequency is expected to increase under climate change\(^{150}\). Whilst some “hard” management was retained,
the floodplain has been restored by decommissioning dikes; restoration is intended to benefit wetland wildlife, provide new recreation and economic opportunities, and improve flood protection\textsuperscript{151}.

**Impacts of rising temperatures can, in some cases, also be combated with ecosystem-based approaches.** In the UK, rising river temperatures could harm freshwater wildlife, notably including brown trout and salmon\textsuperscript{152}. To counteract this, trees and other vegetation can be replanted alongside rivers to reduce temperatures by providing shade; further benefits for human adaptation could come from lowered flood risk and reduced erosion\textsuperscript{152}. Similarly, in cities, increasing green space can help to reduce temperatures whilst improving urban biodiversity; modelling suggests that adding only 10% of green cover to city centres could keep maximum surface temperatures similar to or lower than 20th century levels even under high climate change scenarios\textsuperscript{153}.

**Ecosystem management could help to reduce overall greenhouse gas emissions** (climate change mitigation). Peatland restoration is an example of both climate change adaptation and mitigation, with improved flood management and carbon storage both resulting from better peatland management. Peatland restoration in the UK has already been shown to benefit breeding birds, carbon storage and hydrology\textsuperscript{130, 133}. Another example comes from Belarus, where a partnership co-ordinated by the RSPB was established to restore degraded peatlands. Between 2009 and 2011, over 17,000 ha (hectares) of drained and degraded peatland was re-wetted\textsuperscript{154}. The restoration could reduce carbon emissions by an amount equivalent to 30,400 tonnes of CO\textsubscript{2} each year, providing substantial climate change mitigation benefits\textsuperscript{154}. Threatened bird species such as the aquatic warbler and greater spotted eagle should benefit from the restored habitat, and local human communities should benefit from increased fish populations and cranberry production\textsuperscript{154}.

Successful application of ecosystem-based adaptation principles is increasing, but there is still more to learn about how and where such approaches can be applied, and how they compare in cost and efficacy to alternative adaptation measures. **Integrating wildlife into climate change adaptation and mitigation measures could provide much wider benefits than considering humans separately from the rest of the natural world.**

**Case study: Wallasea Island Wild Coast (Ausden, 2014; Ausden, 2015)\textsuperscript{118, 155}**

Wallasea Island on England's Essex coast is the subject of a major project to provide valuable habitat for wildlife. This started with a scheme to compensate, under the EU Birds Directives, for loss of intertidal habitat to port development in the region. It has subsequently expanded to compensate more broadly for the loss of coastal and intertidal habitats in the area and nationally, and to aid adaptation to sea-level rise.

There have been large, historical losses of saltmarsh in Essex through land claim, with the county now retaining only around 2,000 ha of saltmarsh, from an estimated 40,000 ha in the 14th century. Until recently, the island was low-lying farmland protected by sea walls. However, the sea walls were of low flood defence standard, raising the risk of them being breached during a storm surge and to upgrade them would be highly costly. Uncontrolled breaching would have big consequences for the rest of the estuary, with the associated increased volume of water flowing into and out of the rest of the estuary impacting navigation and the
estuary’s existing conservation interest, as well as increasing pressures on flood defences in the surrounding area.

Wallasea Island before controlled breaching of the seawall, showing landscaping to create creeks, islands and pools that will allow important intertidal habitats to form.

Photo credit: BAM Nuttall.

The RSPB, in partnership with Crossrail, Defra, the Environment Agency and Natural England, has re-created intertidal habitat through managed realignment on part of the island, which will provide benefits for wildlife together with a range of benefits for people. Crossrail, Europe’s largest infrastructure project, is the development of a high frequency, high capacity railway for London and the South East of England. Using clean soil excavated during the Crossrail project, the level of the island has been raised so that following flooding, the increase in volume of water flowing into and out of the rest of the estuary will be kept within acceptable limits. Landscaping to create creeks, pools, islands and lagoons has been combined with the controlled breaching of sea walls to introduce tidal flooding, leading to the re-creation of various intertidal habitats. These will provide valuable habitat for a range of species, including wading birds, rare plants and invertebrates. The design of the site is also intended to provide suitable breeding habitat for spoonbills, and so facilitate their re-colonisation of the UK. Furthermore, the project benefits people by storing water in the event of storm surges and thereby reducing pressure on flood defences in the surrounding area, sequestering carbon in buried sediment, and providing recreation opportunities.
Wallasea Island shows how, with careful planning, big benefits can be provided for both people and wildlife adapting to climate change.

Map of Wallasea Island Wild Coast

Map of the current and intended habitats on Wallasea Island. The top map shows the whole island, indicating the range of habitats, while the lower map shows greater detail for Jubilee Marsh on the east of the island.

Figure reproduced courtesy of Malcolm Ausden.
12) Implications for conservation

This report provides widespread evidence that climate change is already affecting wildlife across Europe, and that impacts are likely to escalate in the not-too-distant future. This will add to, and interact with, many other pressures faced by wildlife. How should we respond?

- **Greenhouse gas emissions should be reduced to limit the degree of warming**: although wildlife is already being affected, future climate change is likely to lead to more severe impacts. Reducing emissions is a key step in reducing impacts.

- **Species’ ranges are changing as they track suitable climate**: providing sufficient, suitable habitat is key in ensuring species can track the conditions to which they are adapted.

- **Some species could benefit from climate change, at least at certain geographical scales, whilst many could be adversely affected**: resulting changes in ecological communities should be monitored to ensure efficient targeting of conservation action, and identification of mechanisms behind impacts.

- **Extreme weather will increasingly affect populations, and wider climatic conditions could become less suitable for many species**: under these circumstances it is important to identify site and landscape management actions to aid population resilience and adaptation.

- **Non-climatic pressures on wildlife should be reduced**: As climate change will have an increasing impact on wildlife, it will be important to ensure other threats are reduced.

- **Robust protected area networks are essential** now, and will continue to be essential under climate change. Protected areas support larger populations and more diverse communities, and aid colonisation of new areas and survival in existing ranges.

- **The existing protected area network could be enhanced**: “more, bigger, better and joined” sites\(^{156}\) will aid population persistence and species’ movement across the landscape.

- **Ecosystem-based adaptation could aid human climate change adaptation and benefit biodiversity at the same time**: Working with nature could provide much wider benefits than considering humans separately from the environment.
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