Climate Change and Nature Conservation in Britain and Ireland

MONARCH - Modelling Natural Resource Responses to Climate Change

The UK Climate Impacts Programme (UKCIP)

UKCIP was established by the UK Government in 1997, with the aim of providing a framework for the integrated assessment of climate change impacts. Researchers for MONARCH used the UKCIP98 climate scenarios and data sets, as well as the statistical techniques and several computer models. They also considered their findings in the light of other research undertaken under the UKCIP umbrella, particularly the DEFRA Conservation Policy Review and regional scoping studies. These earlier studies were based on expert opinion and literature reviews, but the modelling in MONARCH supports their findings.

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Paul Sterry, Nature Photographers Ltd (NPL)
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The Climate Change and Nature Conservation in Britain and Ireland was funded by the following organisations.

British Trust for Ornithology

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English Nature

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At a glance - winners and losers of climate space

Climate change presents threats for some species, as well as opportunities for others. Below is a snapshot of the study findings.

**MONTANE HEATH**
This is the most sensitive of all the habitats studied. All species lose climate space.

**Winners** - new

**Losers** - mountain heath (Pyrrhocypripedium) - favers local extinction


**UPLAND HAY MEADOWS**
Species composition is likely to shift, but other studies show that this depends on farmers’ responses to climate change.

**Winners** - great burnet (Sanguisorba officinalis)

**Losers** - globe flower (Ranunculus acris) - wood sedge (Carex selaginoides)

**LOWLAND CALCAREOUS GRASSLANDS**
Changes are likely to be small, but this depends on land use and land management responses to climate change.

**Winners** - dwarf boar’s head (Cerastium auriculatum)

**Losers** - tall sedge (Poa trivialis)

**SALT MARSHES**
Variable species’ response is likely to result in altered species’ composition. Salt marshes may migrate inland as sea levels rise, depending on coastal protection policies.

**Winners** - sea purslane (Spergula arvensis)

**Losers** - common salt marsh grass (Puccinellia maritima)

**COASTAL ESTUARIES**
Robust habitat since the dominant species (beech) loses climate space.

**Winners** - western red deer (Cervus elaphus)

**Losers** - adder’s tongue (Ophioglossum vulgatum)

**WET HEATHS**
Robust habitat since the dominant species (cross-leaved heath) shows no change, but may be adversely affected by lower water availability in the south and east of Britain and Ireland.

**Winners** - marsh heath (Erica tetralix)

**Losers** - common spotted orchid (Dactylorhiza fuchsii)

**COASTAL DUNE SLACKS**
Variable species’ response is likely to result in altered species’ composition. Slacks may migrate inland as sea levels rise, depending on coastal protection policies.

**Winners** - marshes (Cleista sagittata)

**Losers** - common salt marsh grass (Puccinellia maritima)

**BEECH WOODLAND**
The dominant species (beech) loses climate space in the south and east of Britain, but in the north and west the habitat may gain.

**Winners** -

**Losers** - beech (Fagus sylvatica)

**SALT MARSHES**
Variable response for the effects of sea level rise on the density of waterbirds. However, numbers of all waterbirds increased as a result of increasing area.

**Winners** - oystercatcher (Haematopus ostralegus)

**Losers** - common salt marsh grass (Puccinellia maritima)

**FRESHWATER HABITATS**
Impacts will depend on hydrology as well as temperature change, with desiccation in the south and east of Britain and Ireland a particular threat.

**Winners** - beaver (Castor canadensis)

**Losers** - great burnet (Cerastium auriculatum)

**OTHER WETLANDS AND OTHER WETLANDS AND...**

**UPPER MONTANE**

**Winners** -

**Losers** -

**OTHER SPECIES**

**Winners** - large skipper (Ochlodes venata)

**Losers** -

It identifies the potential implications for species and habitats in four environments: terrestrial, freshwater, coastal and marine. Winners and losers emerge, including some species threatened with national extinction.

Climate is one of the key determinates of species’ distributions. As our climate changes, the distribution patterns of species and the composition of habitats will change.

If we are to understand the likely changes and so assess the vulnerability of different species, as well as their ability to adapt, we need to understand how current patterns of distribution are related to our climate.

This was the starting point for developing a biodetection classification for Britain and Ireland, demonstrating which parts of Britain and Ireland share the same climate characteristics now, before using models to predict future impacts on species.

MONARCH identifies whether a suitable climate is likely to be available, but there is no guarantee that a species will be able to move to it. Climate will not be the only factor determining whether the new location is suitable. The ability to move and the ecological suitability of the new climate space will also be vital in determining the future distribution of species in Britain and Ireland. The study also indicates gaps in knowledge and the implications of the research findings for policy makers.

The study, commissioned by a consortium of nature conservation organisations in Britain and Ireland, was carried out under the UK Climate Impacts Programme (UKCIP) - see back page for details.
A changing climate

Nobody can be absolutely sure how the climate will alter over the coming decades. But the world’s leading climate scientists, grouped under the banner of the UN’s Intergovernmental Panel on Climate Change (IPCC), believe that global average temperatures will rise by between 1.4 and 5.8 degrees centigrade over the current century.

Uncertainty arises in projections of future climate because we don’t yet know how society will respond to the threat posed by climate change. But, however swiftly and dramatically we respond, some climate change is now inevitable.

Climate change will not be the same everywhere. Apart from raising average temperatures, it will have numerous other effects on our day-to-day weather, including increases and decreases in rainfall and changes in the frequency and intensity of extreme climatic phenomena.

The MONARCH study has used the UKCIP98 climate scenarios developed by the Hadley Centre at the Met Office and the Climatic Research Unit at the University of East Anglia to explore the possible effects on species. Climate change projections were based on the two most extreme scenarios (termed the Low and High scenarios) to reflect the range of possible outcomes. The scenarios were produced, it was not possible to say which scenario was more likely.

New climate scenarios, due for publication in 2002, based on the revised IPCC projections indicate that temperatures may be higher still. These new scenarios will need to be taken into consideration in future research.

The UKCIP98 scenarios suggest that Britain and Ireland will experience:

- Temperature increases of between 0.4 and 1.6 degrees centigrade by the 2020s and 0.7 to 2.6 degrees centigrade by the 2050s;
- Increases in winter rainfall everywhere, but a decrease in summer rainfall in southern England of as much as 22 per cent by the 2050s;
- Higher evaporation rates that will affect water availability, particularly in the south east of England;
- Sea level rise of as much as 78 centimetres by the 2050s in the south east of England and southern Ireland, but less in the north west of Britain and Ireland.

The climate scenarios provide information on many of the climate variables affecting wildlife. However, quantitative data about some important variables are not available in the UKCIP98 scenarios, such as ocean circulation and wave climates. More data will become available with the new UKCIP2002 scenarios.
**What the study entailed**

**Bioclimatic classification**

Researchers used the statistical techniques of principal components analysis and hierarchical clustering to divide Britain and Ireland into 21 bioclimatic classes, each with their own climate characteristics of biological importance. An initial 89 bioclimatic variables, chosen to reflect the key climatic variables of species distribution, were reduced to the seven variables that best explain the bioclimatic variation across Britain and Ireland. The first four were found to be the most important in distinguishing between the different classes: these were related to rainfall, temperature, wind speed and sunshine.

The classes ranged from the coldest in the Cairngorm mountains, to the warmest in south west England and Wales and along the coast of southern and eastern England; from the wettest in western Scotland to the driest in southern England and eastern Wales; and from the windiest in Snowdonia and Skye to the least windy in central Ireland (see map).

Each class was characterised by active landscape processes – its geomorphology - and by designated conservation sites and habitats of conservation interest. Within each class, a range of dominant, threatened and climatically sensitive species was identified to study with impact models. Six landscape types affected by geomorphological processes were also selected for further study, with karst, the distinctive network of caves and sink holes, being chosen as an example of a sensitive terrestrial habitat for the coastal environment; five coastal habitats of conservation concern were chosen, along with two estuaries for detailed modelling of impacts on wading birds.

**Impact models**

Impacts of climate change on the geographical distribution of 50 species associated with 12 habitats of conservation concern were investigated using the SPECIES (Spatial Estimator of the Climate Impacts on the Envelope of Species) model, originally developed under RegIS, a complementary study in the UKCIP framework. SPECIES uses a complex computer program (neural network) to characterise the currently suitable climate space for a species and to estimate likely changes in its spatial distribution by the 2050s. This way it is possible to see how the climate space for individual species could contract, expand or shift as the climate changes.

Changing patterns of rainfall are especially important for freshwater environments, such as wetlands. Here the SPECIES model was supplemented by water availability and wetlands models to investigate impacts on moisture sensitive plants and amphibians.

In coastal environments, impacts on the density and numbers of key estuarine birds were investigated using models based on estuary shape (estimated from high precision topographical maps and predictions of sea level rise) and climate variables. Conceptual models were also developed to explore the geomorphological sensitivity of coastal sand dunes, salt marshes, vegetated shingle ridges, seagrass beds and rocky coastal platforms to climate change.

In marine environments, a range of benthic ecosystems were studied to investigate their sensitivity to climate change through changes in sea level, sea surface temperature and other variables. Research on consequences for marine habitats is not far advanced, so the method involved building up baseline information for key marine features and species via literature reviews and conceptual models.

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2 The SPECIES model was originally developed as part of a jointly funded project between DEFRA and UKWIR: ‘Regional climate change impact and response studies in East Anglia and North West England (RegIS).’

Each colour represents a different class sharing bioclimatic characteristics. The diagram illustrates clearly the greater diversity of bioclimate in the north of England, Scotland, Wales and parts of Ireland.
Climate change appears to present threats for some species, as well as opportunities for others.

While temperature, rainfall, rates of evaporation and sea level rise are critical factors in understanding the impact of climate change on species, there are other significant factors where data is not yet available.

These include changes in the intensity of rainfall events, the numbers of days with snow, maximum wind speed and direction, storminess and any alternations in ocean circulation. Despite these remaining uncertainties, we can reach some tentative conclusions about the future distribution of species in Britain and Ireland.

Terrestrial habitats
- In general, species with northerly distributions will lose suitable climate space in Britain and Ireland. The species in this category are amongst the most vulnerable, because these losses are likely to be realised and will lead to fragmented habitats and decreased populations. Balanced against this are species with more southerly distributions that could expand their climate space. For these species the issue is their ability to migrate and the availability of suitable habitat, as vulnerability can occur where there will be little or no overlap between the current and future distribution.

- The responses of plants are highly variable, illustrating the individualistic response of species. Those with a northern distribution, such as globe flower (Trollius europaeus) and trailing azalea (Loiseleuria procumbens), could decline while those with a southern distribution, such as sea purslane (Atriplex portulacoides) and white-beaked sedge (Rhynchospora alba), could expand.

- As with plants, the impacts with a northern distribution, such as the mountain jotun (Draba sibirica) and large heath (Coenopyrum tullia) butterflies, could lose suitable climate space, while those with a southern distribution, the azure damselfly (Coenonympha puella) and the large skipper butterfly (Ochthis venata), could gain it. The amphibians showed a variable response with a reduction in climate space in some current areas of suitability, but a potential gain in southern England.

- The responses of bird species to climate change are also likely to be highly variable. Some, such as the capercaillie (Tetrao urogallus) and red-throated diver (Gavia stellata), could decline while others, such as tufted tit (Aegithalos caudatus), black-throated diver (Gavia stellata), yellow wagtail (Motacilla flava) and red-wattled lapwing (Vanellus Avocatus), may expand their ranges. Several bird species, including willow tit (Parus montanus), nightingale (Luscinia Megarhynchos) and nuthatch (Sitta europaea), showed a positive response to moderate climate change (low scenario) but with severe climate change (high scenario) their distributions may either contract significantly or become more fragmented in southern England.

- The collective results for species provide an indication of the response of habitats. Montane heaths and for a lesser extent upland hay meadows and pine woodlands are seen as being vulnerable to climate change. Upright oak woodland, birch woodland and peat bogs could also be susceptible due to species’ issues in southern and eastern England. The species’ response in other habitats was much more variable and this may lead to changes in the species’ composition of habitats.

Karat landscapes
- Karst landscapes are made up of distinctive limestone outcrops and caves. In four karst case study sites, the Burrow (CIX Carea), the Yorkshire Dales, the Cullagh karst (Co. Fermangh) and Asity karst (Scotland), mean annual water availability (rainfall minus evapotranspiration) is predicted to rise, resulting in a modest increase (less than 10%) in dissolution rates. This will produce increased erosion of surface areas, and increased availability of dissolved calcium carbonate for formation of speleothems and tufa deposits. In the Mendip Hills, where mean annual water availability is predicted to decrease, dissolution rates will slow down by as much as 50%.

- Sensitive karst features such as tufa, speleothems and boulders are likely to be most clearly affected by climate change. The impacts of climate change on geomorphological processes will probably be less noticeable than effects from local human activities, although there may be synergistic associations between the two.

Freshwater habitats
- Water availability (rainfall minus evapotranspiration) is likely to increase by up to 40 mm in winter (December to February) throughout Britain and Ireland. This could lead to increased ponding and flooding. Raised bogs, wet heaths and coastal flood slacks may benefit. In summer (June to August), there is likely to be a small increase in water availability in north west Ireland and north west Scotland, little change in the area immediately southeast east of these regions, and a decrease elsewhere. This is likely to be most severe (up to 110 mm decrease) in south east England. This reduced water availability would lead to the drying of wetlands habitats with consequent changes in their species composition.

- Rain bogs, wet heaths, coastal flood slacks, drought-prone acid grassland and beach woodland could be adversely affected by the lower water availability in south east England and to a lesser extent south east Ireland. Some chalk grassland species predicted to lose suitable climate space in the south east could be further affected by decreased water availability.

- A local scale hydrological model run for a site in East Anglia shows similar decreases in summer water levels and this could result in the three modelled species, the great bunnet (Sanguisorba officinalis), adder’s tongue (Erebia ligeia) and large heath (Erebia epiphron), having a loss of suitable climate space in Britain and Ireland. The species in this category are amongst the most vulnerable, because these losses are likely to be realised and will lead to fragmented habitats and decreased populations. Balanced against this are species with more southerly distributions that could expand their climate space. For these species the issue is their ability to migrate and the availability of suitable habitat, as vulnerability can occur where there will be little or no overlap between the current and future distribution.

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Terrestrial and freshwater habitats

The impacts of climate change on the distribution of suitable climate space were modelled for 33 plant, four insect, two amphibian, one mammal and 10 bird species associated with 12 habitats of conservation concern. Responses were highly variable, with some of each category losing and some gaining climate space.

Impacts on flora

Montane heaths

Montane heaths occur high in the wind-swept mountains of Scotland, with outposts in the uplands of northern England, Wales and Ireland. Their vegetation includes dwarf willow (Salix herbacea), along with heathers, mosses, sedges and herbs. Though usually remote from human habitation, montane heaths are already under threat from human activities, with many species restricted by flew, grazing, human feet and soil acid. Montane heaths are also the most sensitive to climate change of all the habitats analysed. Under the various climate change scenarios, all montane heath species show a loss of climate space.

The dwarf willow (Salix herbacea) will probably disappear from Wales and most of England and Ireland by the 2050s, remaining largely in the Cairngorms and Highlands of Scotland. Much the same is likely to happen to the trailing azalea (Loiseleuria procumbens). This is expected to be progressively lost from the southern Pennines, the Lake District and North York Moors and even perhaps the Cheviots by the end of the 2050s, followed by the Southern Uplands of Scotland and its few remaining Irish outposts by the 2050s.

A similar response is expected from the sedges Carex (genus) and Eriophorum, which is expected to disappear from the Pennines, Snowdonia and Macgillycuddy’s Reeks (Co. Kerry). But the prognosis for this species is far from clear because, while other research shows that warmer temperatures may be damaging for the plant’s root growth, the extra warmth could, according to studies in Ireland and Sweden, encourage its root to grow larger, so improving reproductive success.

Upland hay meadows

Upland hay meadows are found on the better soils in the higher parts of England, Wales and Scotland. Their survival will depend crucially on how farmers respond to climate change and other pressures. But even where current management regimes persist, climate change will almost certainly cause substantial shifts in species composition.

Among typical meadow species, wood crane’s-bill (Geranium sylvaticum), a petal purple meadow plant, could disappear from eastern and much of its lower terrain-alpine in England and Wales. And the cow globe flower (Plutus europaeus) shows a decline in climate space and other research suggests it may also prove susceptible to the disappearance of the Choisotricha flies that are vital to its pollination.

But as these species lose out, the herb great bent (Sanguisorba officinalis) could benefit from climate change, expanding its climate space to the way the Scottish Highlands, as far as the Shetlands and Orkney.

Upland oak woodlands

Oak woodlands occupy many of the poorer soils and steeper slopes of the upland north and west of Britain and Ireland. Oaks themselves may grow vigorously enough under warmer conditions, and may colonise mountain sides that are currently too cold for them. But the other vegetation of these woodlands is likely to suffer seriously as soils dry out in summer.

Of three forest plants studied, two are likely to lose climate space in more southern areas. One is the hay-scented buckler-fern (Dryopteris aemula), to higher altitudes, aided by an increased growth rate. It could, however, be adversely affected by increased windthrow, as the less frozen soils provide less anchorage, loss of biomass and regeneration ability through increased temperatures and competition from less cold tolerant species.

Among typical meadow species, wood crane’s-bill (Geranium sylvaticum) is likely to show little change.

Beech woodlands

The beech woodlands of southern and eastern England and south Wales could be major casualties of climate change. By the 2050s, their climate space may be lost in East Anglia and parts of southern England. In theory, the tree could gain ground further north, across central England and Wales and into Scotland. But tree migration is slow and it is far from clear that this will happen. Other research has shown that beech (Fagus sylvatica) is drought-sensitive, and would be expected to die back as soils become drier in the summer. The departure of the beech may be hastened by the invasion of more drought-tolerant tree species such as oaks. The similarly distributed yew tree (Taxus baccata) is also more resistant to drought and model results show that it could expand its range. Other species found in the under-storey of beech woods, such as sarsaparilla (Sanicula europaea) could fare better, though other work casts doubt on the sarsaparilla’s ability to flower properly in drought conditions.

Chalk grasslands

Carraguel grasslands on well-drained chalk and limestone soils are one of the distinctive landscapes of lowland England and parts of Wales and Ireland. But as soils dry out in summer, some plants, such as the dwarf thistle (Cirsium nummularium), could become unviable. Others, such as the yellow-wort (Blackstonia perfoliata) and common rock-rose (Helianthemum nummularium) may fare better if they can find their way north to newly available climate space. Further modelling work is required to increase confidence in predictions for a wider range of species.

Native pine woodland

Native mixed woodland, dominated by pine, used to be found over large areas of the Scottish Highlands, but it has been reduced to about 1% of its former range and is now only found in the Grampians and the northern and western Highlands of Scotland. Climate change could lead to the spread of Scots pine (Pinus sylvestris) to higher altitudes, aided by an increased growth rate. It could, however, be adversely affected by increased windthrow, as the less frozen soils provide less anchorage, loss of biomass and regeneration ability through increased temperatures and competition from less cold tolerant species.

It may be possible to maintain the dominant species in this habitat, but its total species composition is likely to change. A threatened species, twinflower (Linnaea borealis) is predicted to lose a significant proportion of its currently suitable climate space by the 2050s High scenario.

Wet heath and acid grassland

While these habitats may cover the same amount of land in the future, they may have to shift their location in response to climate change. Wet heaths may expand in Ireland and in some northern and western areas of Britain where increased winter rainfall waters up formerly dry heath. But in south east England wet heaths could dry out and revert to dry heath. Cross-leaved heath (Erica tetralix), which is currently found throughout Britain, may have to give ground to more suitable species, such as bell heather (Erica cinerea). Overall, populations of species such as cross-leaved heath and its larger associate marsh gentian (Gentiana pneumonanthe) are likely to remain stable in Britain.

As wet heaths dry up in southern England, they are likely to be replaced by an expansion of the region’s acid grasslands. But some species common on these grasslands may disappear as drought intensifies. The common stockbell (Erodium cicutarium) is currently widespread in mainland Europe, though in Britain it is currently confined to the dry grasslands of Norfolk and Suffolk. Spanish catchfly (Silene otites) however is common in mainland Europe, though in Britain it is currently confined to the dry grasslands of Norfolk and Suffolk. Spanish catchfly (Silene otites) is predicted to lose a significant proportion of its currently suitable climate space by the 2050s High scenario.
Peat bogs

Peat bogs are among Europe's rarest and most threatened habitats. There are several types of peat bog, each with characteristic species. Britain and Ireland hold a significant proportion of the world's total area of certain types of bogs. Summer drought is likely to dry out the few remaining bogs in southern and central England, and affect those in southernmost Scotland and Ireland. But this will be counterbalanced by better conditions for bog growth further north, thanks to increased rainfall, particularly in winter.

Suitable climatic conditions will persist for some types of peat bog, but the species composition of the plant communities may well change. The dominant vegetation of most bogs is sphagnum moss, of which there are many species. The study investigated the likely future extent of Sphagnum papilliflorum. Its climate space is likely to remain and possibly enlarge across Britain and Ireland. A similar response is seen for other bog species such as bog myrtle (Myrica gale) and white beaked sedge (Rhynchospora alba), but more northern species will probably lose a significant part of their current distribution. One such species is likely to be the cloudberry (Rubus chamaemorus), which may find conditions too warm and could disappear entirely from Ireland and Wales, most of England and much of south and east Scotland. Another loser could include bog rosemary (Andromeda polifolia).

Wetlands

Wetland habitats are home to many rare plants in Britain and Ireland. Many wetland species are likely to be at risk as climate change produces more extreme weather and greater seasonal variation in rainfall, as well as enhanced summer evapotranspiration. For most of Britain and Ireland, extra rainfall is expected to ensure more water is available in winter — sometimes causing flooding. This is good news for lakes, bogs, wet heaths and for vegetation preferring wet areas amid coastal dunes. But it will only be wetter throughout the year in the far north of Scotland and Ireland. The timing of rainfall will be important in many wetlands in these areas. Standing water can be essential in winter, but lethal in spring or summer. Much Icelandic vegetation requires standing water, but it stands too long, some species will die. So extra summer rainfall could be damaging even to wetlands.

In much of Britain and Ireland, there is likely to be significantly less rain than at present in summer. This will be exacerbated by increased rates of evaporation in the warmer air. So the amount of water available across most of England and south east Ireland will in all probability be substantially less than today between March and October. The result is likely to be a widespread desiccation of many wetland habitats. This will be most severe in south east England.

For wetland habitat, modelling from SPECIES needs to be combined with the results of a hydrological model in order to reveal the true effects of climate change on species. For instance, adder's tongue (Ophioglossum vulgatum) and skelly-leaved buttercup (Ranunculus sceleratus) are projected under the SPECIES model to expand their range from parts of England to cover the whole of Britain and Ireland by the 2050s. But falling water levels and drought in summer could instead reduce their ranges. The buttercup, in particular, could become rare. Even more vulnerable may be the slender-leaved pondweed (Potamogeton filiformis), an aquatic plant that is currently found in many Irish lakes, such as Lough Neagh and Strule Lakes, and in Anglesey and around the Scottish coast. By the 2050s, none of these areas are expected to have suitable climates. This pondweed should have climate space on a few mountain sides in Scotland and northern England, but all are distant from its current habitats.

Impacts on other plant species

Some plants have ways they face special survival problems. The study investigated the likely fate of the Norwegian mugwort (Oenanthe nemorosa), an Arctic plant that is globally rare and found in Britain and Ireland only on the summits of those northern Scottish mountains. None of these are likely to remain suitable habitats under climate change. One other mountain top may become climatically suitable for the species in the 2050s. However, it does not overlap with its current distribution. So the mugwort, in its current mountain location, has no natural way to get to its potential home.

Impacts on fauna

Amphibians

The natterjack toad (Bufo calamita) is an increasingly rare animal listed under the British Wildlife and Countryside Act and similarly protected in Ireland. It lives among sand dunes, grazing mammals, Irish heaths and salt marshes in south east England, Merseyside, Cumbria and County Kerry in south west Ireland. Its long-term decline has been arrested in the last 30 years by protecting its habitat from destruction. But all that could be undermined by climate change.

The species is vulnerable to changes of both temperature and wetness. Its reproductive activity and early development both depend on abundant moisture. In sand dunes, it relies on temporary pools to breed. But, particularly in south east England, these pools may generally disappear earlier in the year. Climate scenarios for the 2020s show the species' climate space disappearing in most of its current habitats. By the 2050s, a range of new climate spaces may have emerged - for instance in the Midlands; south west England and south Wales.

However, the long intervening period of unstable climate may mean the natterjack toad is unable to claim this new territory. Similarly rare is the great crested newt (Triturus cristatus), but modelling of its climate space suggests little change.

Insects

Many insects can expect to do well as temperatures warm; feeding better, living longer and reproducing faster. Being able to fly, they are more likely to find their way to potential new climate space than plants. Typical is the butterfly known as the large skipper (Ochlodes venata), breeds mainly in the spring and summer in England and Wales, but is absent from Ireland and only inhabits south west Scotland. It will probably invade most of Ireland by the 2050s and in Scotland it is likely to spread through the Central Valley and up the east coast.

Likewise, the red-throated diver (Gavia stellata) breeds only in northern Scotland. Studies have shown it can disperse by almost a kilometre a year. In contrast, the mountain ringlet (Andromeda polifolia), which is currently found only in a few locations in the Lake District and Scotland, is likely to become extinct in Britain. This butterfly is already listed under the British Wildlife and Countryside Act as a species of conservation concern, but conservation action won't be possible if its climate space entirely disappears from Britain, as the models predict for the 2050s.

Birds

Like insects, many birds should find it difficult in accommodating themselves to shifting climatic zones. However, despite being mobile, many birds display strong associations with particular habitat types that provide food and suitable breeding and wintering conditions. They could move, but will they? Many birds living in Britain have not moved to similar climatic areas in Ireland, perhaps through an inability to cross the Irish Sea.

The species’ predicted responses to climate change showed marked differences, with the capercaillie (Tetrao urogallus) being the most vulnerable. The capercaillie lives today in patches ofcool climate space among Scottish Highland conifer plantations and Caledonian pine woods. The bird is already in serious decline and is predicted to lose 99% of its remaining climate space by the 2050s under the High scenario.

Likewise, the red-throated diver (Gavia stellata) breeds only in northern Scotland and in a few locations in the north west of Ireland. Although most areas of current suitability show little change, a loss of climate space is predicted for Osprey under the 2050s High scenario, where its population is currently stable. Large numbers over-winter on the coasts of Britain and Ireland, where it prefers shallow inshore waters and sandy bays could be affected by sea level rise.

A third northern bird, the snow bunting (Plectrocnemia rimei), breeds mainly in the Grampians and north west Highlands of Scotland on the highest parts of the mountains near late-lying snow beds, which ensure a plentiful supply of insects as the snow melts through the summer. Suitable climate space is centred on the western Highlands under all scenarios. However, these results do not take account of possible changes in snow covers if the snow disappears, then food could be in short supply, so breeding snow buntings could become scarce as they retreat further north to breed.

Over-wintering snow buntings presently have a much greater range and can be found around the coasts of Britain and Ireland, but their presence too might decline if over-wintering conditions further north become less severe.
Impacts on karst landscapes

Climate change will also affect nature conservation areas through impacts on geomorphological processes which in turn may trigger a whole range of ecological impacts. The study looked at the prognosis for karst scenery - the distinctive networks of caves and sink holes that characterise limestone areas.

One of England’s largest and most treasured karst systems is the Mendip Hills of Somerset. It faces possibly major changes in the processes that mould its distinctive features, such as cave stalagmites and stalactites. These are formed by redeposition of calcium carbonate dissolved from limestone. If dissolution rates decline then there will be less calcium carbonate available to form stalagmites and stalactites.

The Mendip Hills contain 200 caves, including the famous Wookey Hole, many of them rich in such features.

The hills that supply water to the cave systems are expected to receive much less rainfall in future. And higher temperatures will likely also increase evaporation rates. The combination of these factors, which is now laying its eggs significantly earlier, and fledging more chicks from the nest.

Similarly, the willow tit (Parus montanus) may need to move north in Britain. While modest changes in climate will have little effect on the potential climate space for the willow tit, under the High scenario it would need to abandon its homes in the broadleaf woodlands of southern England and Wales as they become hotter and drier. Its climate space moves to northern Wales, central Scotland and the Borders. However, it may be unable to realise these northward expansions in its distribution as it is a resident, sedentary species and adults tend to defend the same areas in consecutive years. Further, in northern Scotland it may find that the heavily grazed woodlands offer little of the deadwood that willow tits need for nesting.

The turtle dove (Streptopelia turtur) is a long-distance migrant that could spread west into southwest England, Wales and Ireland. But the bird is in steep decline in Britain today. The reasons are not clear but are probably connected to loss of the seeds of weeds on which it feeds, or to changes in weather conditions on its wintering grounds. It is unclear whether improvements in climate conditions will be sufficient to halt or reverse the current trend. The yellow wagtail (Motacilla flava) is another long-distance migrant with a declining population in Britain. Its breeding range is contracting into a core area of the East Midlands, perhaps because of the loss of grassland elsewhere. Again, its climate space is predicted to expand in the coming decades in southern England and Wales, including a substantial expansion in Ireland by the 2050s under the High scenario, but it is not clear whether that will be enough to reverse its decline.

The nuthatch (Sitta europaea) is already expanding its range, but has similar potential to spread even further north and west, even as far as Ireland and the Outer Hebrides by the 2050s under the High scenario. But it may not get far because of its sedentary behaviour. It is also a woodland species, and it is unclear whether there would be sufficient mature broadleaf woodland to support populations in many parts of Ireland. Under the High scenario, its climate space is also predicted to retract markedly in south east England and around the south coast, though the large populations in the south and west of England and Wales are likely to remain. Mild winters are likely to benefit this species as its breeding density is often linked to winter food supplies.

The trust for Ornithology has shown it is now laying its eggs significantly earlier, and fledging more chicks from the nest.

Similarly, the nightingale (Luscinia megarhynchos) is currently in a slight overall decline, possibly due to a reduction in habitat quality on its breeding or wintering grounds. The study indicates that moderate or short-term climate change will benefit the nightingale in Britain. Its response will depend on what is currently affecting its decline and the interaction between these factors and climate. Though long-distance migrants, the birds show strong individual fidelity to breeding sites. This fidelity may limit its tendency to colonise coastal south west England, Wales and Ireland - all predicted to offer suitable climate under the High scenario. And in the longer term, soils in its heartland, south east England, may dry out so much that the insects on which it feeds disappear, having severe impacts on the population.

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Birds from southern England should do best. The wood warbler (Phylloscopus sibilatrix) should prosper as its climate space expands into south west England, coastal Wales, northern England, southern and central Scotland and Ireland. Indeed it has recently begun to breed regularly in Scotland and Ireland.

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Coastal and marine habitats face the twin influences of climate change and rising sea levels. The interplay between the two makes assessing the likely future state of habitats and their species complex.

**Impacts on coastal species**

Many coastal species face similar challenges of altered climatic space to those on dry land. Among plants, the common salt-marsh grass (*Puccinellia maritima*), a pioneering species which is currently found on the seaward side of salt marshes all around the coasts of Britain and Ireland, is expected to disappear from south and east England as it warms. It would depart first from the Thames estuary and, later from everywhere between the Essex estuary in Devon to the Humber. This could have a significant damaging effect on the overall formation of salt marshes in these areas. Another salt marsh species, salt sedge (*Alfinum nivalis*), is predicted to lose its climatic space. Its current northern distribution extends as far south as Wales and the Humber, but by the 2050s, it could be restricted to the coastline north of Aberdeen and Glasgow, and lost entirely from Ireland.

By contrast, sea purslane (*Atriplex portulacoides*), a pioneering species which is currently found on the seaward side of salt marshes all around the coasts of Britain and Ireland, is expected to disappear from south and east England as it warms. It would depart first from the Thames estuary and, later from everywhere between the Essex estuary in Devon to the Humber. This could have a significant damaging effect on the overall formation of salt marshes in these areas. Another salt marsh species, salt sedge (*Alfinum nivalis*), is predicted to lose its climatic space. Its current northern distribution extends as far south as Wales and the Humber, but by the 2050s, it could be restricted to the coastline north of Aberdeen and Glasgow, and lost entirely from Ireland.

Internationally important populations of wading birds that over-winter principally on the estuaries and non-estuarine coasts of Britain and Ireland are already being affected by climate change. Since the early 1980s, the distributions of six of the seven species of rare non-estuarine wader studied — including ringed plover (*Charadrius hiaticula*), curlew (*Numenius arquata*) and redshank (*Tringa totanus*) — have moved northwards and eastwards as winters have become milder. This will benefit birds that are now increasingly wintering on the estuaries of eastern Britain that tend to be milder and have higher densities of prey than the sandy west coast estuaries. With climate change many waterbirds may in future winter further to the north and east of Europe in areas closer to their Continental breeding grounds, currently not available because of their relatively harsh winter climate. Other species were less sensitive to climate change. Britain and Ireland’s assets will only be able to hold the predicted increased number of waders if the effects of climate change on their northerly breeding grounds do not adversely affect the populations of these birds.

Coastal ecosystems can be expected to retreat inland, at least partially compensating for sea level rise. Salt marshes that are inundated at their seaward boundary could reform further up the beach. But along most of the coasts of Britain and Ireland, sea defences designed to protect farmland and human settlements will impede this retreat (commonly termed coastal squeeze). They both block off natural retreat and deprive the coastal waters of the sediment from coastal erosion that is necessary to help create new structures such as salt marshes. The likely resulting loss of salt marshes will damage the populations of many wildfowl and some waders, such as golden plover (*Pluvialis apricaria*) and lapwing (*Vanellus vanellus*), by depriving them of habitat used for feeding and breeding. If defences are maintained and reinforced, the losses of salt marshes could be substantial in many places. But if the response to the rising waters for coastal defence management is to allow a retreat of coastal defences, salt marshes could colonise new areas. There is a practical case for doing this. Salt marshes are widely regarded as an effective natural sea defence, and so could be encouraged as part of an integrated coastal defence policy.

**Rising sea levels**

Future sea level rise is also likely to affect many coastal species. Sea levels will rise fastest in western Scotland and north west England, where the land is gradually rising as a delayed response to the removal of the weight of the ice cap at the end of the last ice age. Here, the sea is likely to gain up to 13 centimetres between now and the 2050s. But in the south east of England and southern Ireland, where the land is sinking, sea levels could be 78 centimetres higher by the 2050s. Rising sea levels will cause widespread erosion of coastal habitats. The salt marshes of Essex, such as the Colne estuary and north Kent in particular, are expected to contract as sea levels rise. Other vulnerable coastal habitats include the marram and sand dunes of north Norfolk and the vegetated shingle beds at Dungeness in Kent and elsewhere along the coast of south eastern England.

Climate change and sea level rise could combine to undermine these fragile, but environmentally extremely valuable, coastal habitats in other ways too. For instance, by submerging sand flats in the inner tidal zone, rising tides could drive deeper sand dunes of the wind borne sand that maintains their structure and prevents them being washed or blown away. The disappearance of moisture from the dunes will deprive them of the vegetation that anchors them. And by altering the shape of many estuaries, rising tides will interfere with the marine processes that cycle sediment and maintain salt marshes, and reduce habitat for the invertebrates on which most waterbirds feed.

As a result of sea level rise, it is predicted that the densities of curlew (*Numenius arquata*), dunlin (*Calidris alpina*) and redshank (*Tringa totanus*) would decrease and that the density of oystercatcher (*Haematopus ostralegus*) would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east coast estuaries (the Deben in Suffolk and the Duddon in Cumbria). And yet the total numbers of each species of wader would increase on two of the east...
Implications of climate change for nature conservation policy and practice

This study underlines the scale and scope of likely impacts of climate change on wildlife and conservation in the coming half-century. These changes will need to be matched by changes in conservation practice; a more forward looking, flexible and dynamic approach to nature conservation will be required.

Existing protected sites will continue as essential reserves for biodiversity, but a greater emphasis on the management of habitats in the countryside and at the landscape scale will be required, to accommodate species’ movements and displacements. Existing measures will continue to be important in achieving conservation objectives, although a number of challenges to both policy and practice also need to be addressed. These include:

- Identifying to what extent it is possible, and how to meet existing conservation commitments and targets as species’ distributions change and the composition of habitats alter.
- Assessing conservation value as species communities and habitat structure change.
- Defining the stages of development of the habitat type, as well as its rate of change.
- Defining acceptable levels of intervention to manage change, particularly with regard to species not recognised as being characteristic of the particular habitat type.

Individualistic responses by species will lead to changes in community composition as the results show for the salt marsh habitat, where common salt marsh grass, sea purslane and flat sedge show differing patterns and rates of response. Such responses raise questions about how existing conservation objectives and targets will remain achievable in the way they are currently framed. We will need to re-assess how objectives and targets are met and, in some cases, if targets are still appropriate. Both the objectives and the mechanisms within nature conservation policy and practice will need to be explored again, taking climate change into account in four main areas.

These are: meeting international commitments and national targets, identifying the locations of existing and future protected sites, the tools and techniques of conservation management and the treatment of non-native species. At the site level, the loss of a species may have significant implications for achieving existing conservation commitments, particularly if the species is the prime reason for the site’s designation or if it forms an essential part of the protected habitat type. As an example, the arctic-alpine habitat type species modelled, Norwegian ringlet, doublenettle and mountain ringlet, all appear to be vulnerable to climate change across the whole of their existing distribution in Britain and Ireland. Their loss would constitute a breach of the EU Habitats Directive which requires countries to take action to ensure that species are maintained. However, it may be possible to maintain overall population numbers in different locations. This work will have to be international in scope, especially where the species in question is found in more than one country. The geographical focus. For instance, if an internationally rare species finds a new home in Britain or Ireland, or where new habitats need to be identified and nurtured for species in decline or threatened with extinction here. Research will also be needed into the possible damaging as well as beneficial effects of invading non-native species.

The MONARCH project has produced a useful set of models and techniques to improve the ability of nature conservation organisations to forecast how climate change might impact on wildlife and geological features. Results from MONARCH will enhance their capacity to provide sound scientifically-based advice on the impacts of climate change on nature conservation, and will assist in the development of adaptation strategies and management options for vulnerable sites. This should ensure that timely action is taken to protect threatened wildlife as climate changes.

Next steps

The next phase of the MONARCH project will address some of these research gaps. The models will be downscaled and advanced to enable the impacts of climate change to be modelled at individual sites. Predictions of the possible future responses of species to climate change will incorporate a dispersal component, which enables the likelihood of species revealing their potential future distributions to be assessed, and a land use component, which enables the availability of suitable habitat to be examined.

The changing distribution of species has important implications for habitat composition and, possibly, functioning. The latter element will be explored at a conceptual level, in the context of the model outputs, in order to increase our understanding of the impacts of climate change on ecosystem dynamics.

The integrated outcomes of the models will be assessed for a number of case study areas and policy and management options proposed relating to conservation objectives.

Policymakers, planners, land users and the public will also need to be made aware of the need to create as well as conserve habitats. We may need new buffer zones to minimise climate stress on existing species and to develop new communities. Ecological ‘corridors’ and stepping stones to allow species to move between existing protected areas will sometimes be needed. Strategies for the translocation of species to new climatic space or to ex situ sites such as botanical gardens, will sometimes also be required.

Gaps in knowledge

The study has also identified a number of gaps in current knowledge and data. For example, better data are needed for current conditions, particularly climatic, soils and habitat data for Ireland, as well as predictive data for future changes in certain aspects of the climate, such as snow, storms, sea surface temperatures and ocean circulation. The impact on species of additional carbon dioxide in the atmosphere also needs to be understood.

Also, it is often not clear which are the key climatic variables that will determine the “climate space” available for species, habitats and geomorphological systems. These need to be further studied, as do the sensitivities of a wider range of species. This will increase confidence in predictions of the evolution of natural habitats.

More research is needed on the potential for and possible rate of migration of species. This is essential for establishing whether, in practice, species will be able to occupy their new climatic spaces. Similarly, additional work is required on how wildlife communities are likely to change, including the future role of non-native species, particularly those likely to migrate from continental Europe. And, throughout, modelling work needs to be supported by additional monitoring.

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