

**European Community Directive
on the Conservation of Natural Habitats
and of Wild Fauna and Flora
(92/43/EEC)**

**Second Report by the United Kingdom under
Article 17**

**on the implementation of the Directive
from January 2001 to December 2006**

**Supporting documentation for making
Conservation status assessments:
Technical Note IV
Conservation status reporting and
Climate change in the UK**

Please note that this is a section of the report. For the complete report visit <http://www.jncc.gov.uk/article17>

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Conservation status reporting and climate change in the UK

1. Introduction

This paper provides an overall background on the impacts of climate change on biodiversity in the UK. Future changes in the climate are identified along with the corresponding impact on habitats and species. General trends are identified across the UK. The paper also provides an overview of the impact of climate change on each specific habitat and species required for reporting under the Favourable Conservation Status (FCS).

This document is primarily based on three recent publications on climate change and biodiversity in the UK; **all expert opinion and research can be referred back to these publications, which are fully sourced by peer-reviewed and other publications.** This document aims to synthesise these bodies of work and paraphrases directly from them. Annex A provides a summary of likely direct impacts of climate change on habitats, ecosystem functioning and species in England. Many of these impacts are likely to hold true throughout the UK.

- MITCHELL *ET AL.*, 2007, *England biodiversity strategy – towards adaptation to climate change*¹. This study was commissioned by Defra to examine the direct and indirect impacts of climate change on biodiversity on five sectors: agriculture; water and wetlands; forestry and woodlands; towns and cities; coasts and seas. The study collates a range of scientific publications to examine what the impacts of climate change are on England's biodiversity. Whilst the publication focuses on England, many of the impacts identified are likely to be the same across the UK.
- HOPKINS *ET AL.*, 2007, *Conserving biodiversity in a changing climate: guidance on building capacity to adapt*². This publication provides guidance to land managers and policy makers on tools to employ to build the capacity of biodiversity to adapt to climate change. As a means of framing this guidance, the publication also discusses the response of biodiversity to climate change in the UK.
- WALMSLEY *ET AL.*, 2007, *Modelling Natural Resource Responses to Climate Change (MONARCH) Phase 3 Report*³. This report is the final culmination of the MONARCH project. Previous MONARCH reports, including *Harrison et al., 2001*⁴ and other modelling work have informed the final phase, which has developed 'climate space modelling' for UK species. The third report focuses on the current distribution of 32 species under the UK Biodiversity Action Plan alongside potential climate change scenarios. The modelling resulted in maps of the possible future 'climate space' for each species under each climate scenario across the UK. The maps are projections of where future suitable 'climate space' may fall and are not an attempt to simulate the future distribution of species as a result of climate change.

¹ <http://www.defra.gov.uk/wildlife-countryside/resprog/findings/ebs-climate-change.pdf>

² <http://www.ukbap.org.uk/Library/BRIG/CBCCGuidance.pdf>

³ http://www.ukcip.org.uk/resources/publications/pub_dets.asp?ID=94

⁴ http://www.ukcip.org.uk/resources/publications/pub_dets.asp?ID=26

This document also draws upon the Branch project⁵ and *Climate Change and Migratory Species by Defra, 2005*⁶.

⁵ <http://www.branchproject.org.uk/>

⁶ <http://www.defra.gov.uk/wildlife-countryside/resprog/findings/climatechange-migratory/index.htm>

2. Overview of Climate Change in the UK

Climate is one of the most important factors that influences the behaviour, abundance and distribution of species, as well as having a strong influence on the ecology of habitats and ecosystems. Changes in the behaviour, abundance and distribution of species are already being observed and linked to climate. Over time these and other changes are likely to become increasingly profound (Hopkins *et al.*, 2007).

The United Kingdom Climate Impacts Programme (UKCIP) has developed a set of climate-change scenarios which project a rise in UK temperature of between 2°C and 3.5°C by the 2080s, with greater warming in the south-east than in the north-west of the UK. There may be more warming in summer and autumn than in spring and winter; in the south-east summer may become 5°C warmer by the 2080s under the 'High' scenario. By the 2050s current typical spring temperatures may occur between one and three weeks earlier and the onset of winter could be delayed by a similar period. Annual average precipitation may decrease slightly but winters may become wetter and summers are likely to become drier, particularly in the south-east where summer precipitation may decrease by 50% by the 2080s under the 'High' scenario. Periods of heavy winter rainfall may become more frequent and account for a higher proportion of winter rain. By the 2080s sea levels in Scotland may be between 2cm below and 58cm above current sea level, with a possible rise of between 26cm and 86cm in south-east England, where the land is sinking due to isostatic readjustment after the last glaciation. (Hopkins *et al.*, 2007)

Table 2.1. Summary of predicted changes in the English Climate up until 2050 based on data from UKCIP.

Variable	Change
Rainfall	<ul style="list-style-type: none"> • Annual rainfall decline by 10% • Summer rainfall decrease by 20-40 % • Winter rainfall increase between 15 and 20 % • Spring and autumn rainfall decrease by 10%
Temperature	<ul style="list-style-type: none"> • Average annual increase 1.5 - 2.5°C • Summer temperatures 3.5°C warmer • Spring, autumn and winter temperatures about 2°C warmer.
Wind speed	<ul style="list-style-type: none"> • Average annual wind speed unchanged • Winter wind speeds increase by 5% • Summer wind speeds decrease by 3%
Sea temperature	<ul style="list-style-type: none"> • Increase by 2°C,
Sea level	<ul style="list-style-type: none"> • Rise of up to 36 cm
Sea pH	<ul style="list-style-type: none"> • Acidity decrease

(sourced from: Mitchell *et al.*, 2007)

3. The response of biodiversity to climate change

The impact of this changed climate on biodiversity will be regional and localised across the UK. Typically species and habitats are most vulnerable to climate change if they exist at the edge of a geographic range (for example species at high latitudes or altitude) or which exist within a narrow ecological range. A number of direct key impacts of climate change upon biodiversity have been identified from observational data and models of future trends. This evidence includes the results of long-term monitoring programmes, experiments simulating climate change on small areas of habitat and modelling studies. The strength of the evidence base does, however, differ greatly between different habitats and species. (Mitchell *et al.*, 2007)

The impact of climate change on UK's biodiversity includes:

- Changes in phenology (including changes in the timings of seasonal events causing loss of synchronicity and increased competitive advantage for some species at the expense of others).
- Shifts in suitable climate conditions for individual species leading to change in species distribution, abundance and range.
- Changes in the community structure and ecosystem function of habitats which species occupy.
- Changes to the composition and structure of plant and animal communities (including arrival of non-natives, loss of native species and increase in pest species).
- Changes to habitats and ecosystems, such as altered water regimes, increased rates of decomposition in bogs and higher growth rates in forests.
- Loss of physical space due to sea level rise and increased storminess.

(Adapted from Hopkins *et al.*, 2007 and Mitchell *et al.*, 2007).

Indirect impacts may also become significant as a result of climate-induced changes in land use having knock-on effects on biodiversity. For example, growing new crops, increases in summer watering and geographical shifts in arable and livestock production could well occur, but how these indirect changes may affect biodiversity remains less certain. (Hopkins *et al.*, 2007)

Modelling of climate space (the geographic area that is projected to have climatic conditions similar to the climate of those areas currently occupied by the species and likely to be climatically suitable for their survival) or potential distribution has been carried out through the MONARCH project, initially for 50 species associated with 12 habitats. The results indicate that there will be both winners and losers across the UK. There is a predicted trend for some northern species, such as those of montane heath, to lose suitable climate space and some species might completely disappear in the UK. Many southern species are likely to gain space with suitable climate. It seems likely that species will respond to climate change differently so that species abundances will change over time within habitats and sites, while species gains and losses may create new combinations of species or communities. (Harrison *et al.*, 2001; Hopkins *et al.*, 2007)

4. Possible impacts of climate change on Annex I habitats

This section draws on specific information generated from the above reports and is broken down based on a broad grouping of Annex I habitats.

4.1 Marine, coastal (including coastal and continental dunes) and halophytic habitats

Some of the most dramatic changes induced by climate change may occur on the coast as a result of sea-level rise exacerbated by extreme weather events, which may lead to alterations in the balance between accretion and erosion on salt marshes, sand dunes and shingle beaches on low-lying coasts. There may also be change to the erosion of cliffs and complex changes in the water regimes and landforms of estuaries and tidal rivers (Hopkins *et al.*, 2007). Sea level rise is a future threat for Atlantic salt meadows and Mediterranean and thermo-Atlantic halophilous scrub. Changes in the water table due to climate change will also impact on dune habitats such as dunes with *Salix repens* and humid dune slacks.

Sea-level rise and an increase in the frequency of storm-surges are likely to lead to loss of coastal habitats and increased variation in salinity conditions. As a result of inundation and erosion of the character of other habitats may change; for example, more extensive mudflats may become sandier and formerly tidal areas will become permanently flooded. Coastal grazing marsh, saline lagoons and salt marsh are also likely to be adversely affected by inundation. Saltwater flooding poses a significant threat to these habitats as many of their associated flora and fauna can only tolerate a finite range in salinity or flooding conditions (Hopkins *et al.*, 2007; Mitchell *et al.*, 2007). Early models from MONARCH suggest there may be both climate space loss and gain for different salt meadow species but it is not clear what the impacts would be on the habitat as a whole (Harrison *et al.*, 2001). Succession of habitats under different climate conditions is a threat, for instance breaches in the dune cordon could result in the replacement of machair by salt marsh.

Where sea walls and other 'hard' features prevent the zone of tidal flooding from moving inland, the extent of intertidal habitat will decline and the associated wildlife will be lost unless suitable habitat is created or allowed to develop naturally through allowing tidal flooding further inland (Hopkins *et al.*, 2007). However, new areas of habitat may form where this is not prevented by hard sea defences. Hard sea defences may themselves act as artificial rocky shores, however, increasing severity and frequency of storms will increase the erosion of existing rocky shores, especially where the rock is soft (chalk for example). (Mitchell *et al.*, 2007)

Changes in water temperature and chemistry and ocean currents will affect individual marine species and in some cases community composition, distribution, abundance, survival of species and modify the structure and composition of habitats. Increased stratification of surface waters has led to upwelling of nutrients and increased the length of the growing season. This is likely to have a considerable impact on ocean productivity, with knock on effects at all trophic levels. Changes in ocean chemistry, primarily increasing CO₂ concentrations and resulting decreases in pH and the saturation rate of calcium carbonate are likely to affect the metabolism, skeletal structure and survival of some organisms. Acidity

changes are most likely to have a direct impact on species with high metabolic rates and pH-sensitive blood oxygen transport (Mitchell *et al.*, 2007).

The timing of biological events is also being affected by climate change. For example, embryonic development, hatching, growth and migration-timing of squid has been influenced strongly by changes in temperature (Mitchell *et al.*, 2007).

Future climate change mitigation activities may also impact on marine and coastal habitats. The location of wind, tidal and wave generation structures, carbon capture and storage (CCS) facilities on submarine structures and other technologies may disturb habitats.

Below is a summary of impacts of climate change on marine, coastal and halophytic habitats (from Mitchell *et al.*, 2007):

- *Changes in phenology*: Changes in migration times, plankton blooms and other biological events have all been shown to be closely linked to temperature.
- *Changes in distribution*: Many intertidal species have spread north and east along the coast in response to climate change and southern species of fish and plankton have shown shifts northward in response to increasing temperatures.
- *Changes in community structure*: Large-scale changes have been observed in fish communities and regime shifts have occurred in plankton communities in the North Sea.
- *Changes in ecosystem function*: the large-scale changes observed in communities and in phenology will have consequences for ecosystem function but this is still a developing area of research.
- *Loss of physical space due to sea level rise and increased storminess*: Large areas of intertidal habitat including salt marsh and mudflats have been lost or are at risk due to sea level rise.

Table 4.1 Summary of possible impacts on specific Annex I habitats

Relevant Annex I habitats		Climate change likely to be a future threat to conservation status of habitat?
Annex I habitat code	Feature name	
H1110	Sandbanks which are slightly covered by sea water all the time	Yes
H1130	Estuaries	Yes
H1140	Mudflats and sandflats not covered by seawater at low tide	Yes
H1150	Coastal lagoons	Yes
H1160	Large shallow inlets and bays	Yes
H1170	Reefs	Yes
H1180	Submarine structures made by leaking gases	Unknown
H1210	Annual vegetation of drift lines	Yes
H1220	Perennial vegetation of stony banks	Yes
H1230	Vegetated sea cliffs of the Atlantic and Baltic coasts	Yes
H1310	<i>Salicornia</i> and other annuals colonising mud and sand	Yes
H1320	<i>Spartina</i> swards (<i>Spartinion maritimae</i>)	Yes

H1330	Atlantic salt meadows (<i>Glaucopuccinellietalia maritimae</i>)	Yes
H1340	Inland salt meadows	Yes
H1420	Mediterranean and thermo-Atlantic halophilous scrubs (<i>Sarcocornetea fruticosi</i>)	Yes
H2110	Embryonic shifting dunes	Yes
H2120	Shifting dunes along the shoreline with <i>Ammophila arenaria</i> ("white dunes")	Yes
H2130	Fixed dunes with herbaceous vegetation ("grey dunes")	Yes
H2140	Decalcified fixed dunes with <i>Empetrum nigrum</i>	Yes
H2150	Atlantic decalcified fixed dunes (<i>Calluno-Ulicetea</i>)	Yes
H2160	Dunes with <i>Hippophae rhamnoides</i>	Yes
H2170	Dunes with <i>Salix repens ssp. argentea</i> (<i>Salicion arenariae</i>)	Yes
H2190	Humid dune slacks	Yes
H21A0	Machairs	Yes
H2250	Coastal dunes with <i>Juniperus</i> spp.	Yes
H1110	Sandbanks which are slightly covered by sea water all the time	Yes

4.2 Freshwater habitats

Open water and wetland habitats may show particularly complex seasonal patterns of change. The most complex range of habitats, and therefore most aquatic and wetland species, are likely to survive in landscapes where there is variation from open water to dry land. A diversity of wetland conditions is most likely to persist where the open waters and wetlands are fed by a combination of surface drainage, ground water and aquifers (Hopkins *et al.*, 2007). There is likely to be greater winter rainfall that could result in increased extents of habitats such as wet heath and coastal dune slack (Hopkins *et al.*, 2007). In the case of rivers an increased incidence of flooding is anticipated. Increased flooding has historically been managed by expensive dredging, straightening and embanking of rivers, a process which is highly damaging to biodiversity (Hopkins *et al.*, 2007). These indirect impacts of climate change, such as increased abstraction of water for human usage, engineering solutions to control flood risk are significant for habitats such as water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation.

Hydrological pressures are important for freshwater habitats. Changes in surface and groundwater hydrology and seasonal fluctuations will have a variety of impacts on freshwater habitats. This is the case for oligotrophic waters and natural eutrophic lakes. In habitats close to sea level there is the threat of sea level rise and salt water intrusion. Some freshwater habitats will also become vulnerable to the risk of colonisation by non-native invasive species as a result of climate change.

There is evidence that climate change will have an impact on the biodiversity of lakes and pools, through a variety of factors including water temperature, water level and interactions with nutrient dynamics. There is a correlation between water temperature and chlorophyll content (indicating abundance of phytoplankton) and spring densities of invertebrate grazers in Scottish lakes (Mitchell *et al.*, 2007). Likewise, in lowland lakes the annual mean water temperatures have increased by around 1°C, with proportionately greater increases in winter

and spring (Mitchell *et al.*, 2007). Future scenarios show that surface temperature will rise and the period of stagnation will extend by up to four weeks and the duration of ice cover decrease by one to two months. The absolute values will depend on the geographical location (latitude, elevation) (Mitchell *et al.*, 2007).

A recent Dutch review cited in Mitchell *et al.*, (2007) concluded that the impact of climate change on lakes would be likely to:

- Reduce the numbers of several target species of birds.
- Favour and stabilise cyanobacterial dominance in phytoplankton communities.
- Cause more serious incidents of botulism among waterfowl and enhance the spreading of mosquito borne diseases.
- Benefit invasive species originating from the Ponto-Caspian region.
- Stabilise turbid, phytoplankton-dominated systems, thus counteracting restoration measures.
- Destabilise macrophyte-dominated clear-water lakes.
- Increase the carrying capacity of primary producers, especially phytoplankton, thus mimicking eutrophication.
- Affect higher trophic levels as a result of enhanced primary production.
- Have a negative impact on biodiversity which is linked to the clear water state.
- Affect biodiversity by changing the disturbance regime.

Thus, predicting the response of wetlands and aquatic habitats to changed climate one must consider the differences in plant community structure, biogeochemistry and hydrology that characterise and differentiate fens and bogs, and indeed the whole spectrum of wetland types (Mitchell *et al.*, 2007).

Climate change will affect the functioning of rivers, lakes, pools and wetland habitats by affecting river flows, carbon fluxes, nitrogen mineralisation and denitrification, precipitation, water temperatures, chemical quality, water stratification, oxygen supply, ground water recharge, flooding regimes and evaporation. This will result in:

- *Changes in phenology*: mediated through both water and air temperatures and leading to changes in timings and rates of larval development and loss of synchronicity e.g. early spawning and slow development in amphibians.
- *Changes in distribution*: will occur in response to alterations in hydrological conditions and/or temperature. Examples include fen species which are at the southern edge of their range and may be lost as climate warms beyond their tolerance range.
- *Changes in community structure*: have been observed across the full range of freshwater aquatic habitats and examples include the changes in relative abundance observed for phytoplankton in the water column.
- *Changes in ecosystem function*: may result from alteration in rates of microbial activity leading to changes in nutrient availability and possible release of greenhouse gases e.g. CO₂, CH₄ particularly from peat lands and wetlands. (Mitchell *et al.*, 2007)

Table 4.2 Summary of possible impacts on specific Annex I habitats

Relevant Annex I habitats		Climate change likely to be a future threat to overall conservation status of habitat?
Annex I habitat code	Feature name	
H3110	Oligotrophic waters containing very few minerals of sandy plains (<i>Littorelletalia uniflorae</i>)	Yes
H3130	Oligotrophic to mesotrophic standing waters with vegetation of the <i>Littorelletea uniflorae</i> and/or of the <i>Isoëto-Nanojuncetea</i>	Yes
H3140	Hard oligo-mesotrophic waters with benthic vegetation of <i>Chara</i> spp.	Yes
H3150	Natural eutrophic lakes with <i>Magnopotamion</i> or <i>Hydrocharition</i> -type vegetation	Yes
H3160	Natural dystrophic lakes and ponds	Yes
H3170	Mediterranean temporary ponds	No
H3180	Turloughs	No
H3260	Water courses of plain to montane levels with the <i>Ranunculion fluitantis</i> and <i>Callitricho-Batrachion</i> vegetation	Yes

4.3 Temperate heath and scrub and montane habitats

Lowland heathland communities are sensitive to climate change and a decrease in climate space has been predicted. Wet heaths and peatlands may be more sensitive to climate change than dry heaths, with these habitats declining in area by 45% and 25% respectively between 1987 and 1996 in Dorset. In South-eastern England it is predicted that as the wet heaths dry up under climate change, they are likely to be replaced by an expansion of the region's acid grasslands (Mitchell *et al.*, 2007).

The balance between the three dominant heathland communities of acid grassland, heather (*Calluna vulgaris*) and bracken (*Pteridium aquilinum*) will shift as changes in climate affect the relative competitive ability of these species through effects on biomass production and nutrient availability. With a prediction for drier, hotter summers, lowland heaths will be at increased risk from fire (Mitchell *et al.*, 2007).

Upland heath and montane habitats are probably the most vulnerable habitat to climate change. Mountain top species are most at risk from climate change because they have nowhere to retreat to as the climate changes. Local extinction of some of the species they support, such as the mountain ringlet and dwarf willow, is likely. (Mitchell *et al.*, 2007). Most of the UK research on climate change and montane habitats is based in Scotland, but the conclusions that rare, isolated and habitat specialists are particularly susceptible to climate change also applies to English and Welsh montane species (Mitchell *et al.*, 2007). Siliceous alpine and boreal grassland habitats are threatened outside Scotland where it is at the edge of its range. Alpine and subalpine calcareous grasslands could also be affected if changes in temperature and/or rainfall affect the distribution of the constituent species.

The restricted or patchy distribution of the montane species makes it more difficult to model their current distribution and thus to predict the effects of climate change. Many montane species are currently at their southern limit in Britain and are all very sensitive to climate change (Mitchell *et al.*, 2007; Walmsley *et al.*, 2007).

Table 4.3 Summary of possible impacts on specific Annex I habitats

Relevant Annex I habitats		Climate change likely to be a future threat to overall conservation status of habitat?
Annex I habitat code	Feature name	
H4010	Northern Atlantic wet heaths with <i>Erica tetralix</i>	Yes
H4020	Temperate Atlantic wet heaths with <i>Erica ciliaris</i> and <i>Erica tetralix</i>	Yes
H4030	European dry heaths	No
H4040	Dry Atlantic coastal heaths with <i>Erica vagans</i>	No
H4060	Alpine and Boreal heaths	Yes
H4080	Sub-Arctic <i>Salix</i> spp. scrub	Yes
H5110	Stable xerothermophilous formations with <i>Buxus sempervirens</i> on rock slopes (<i>Berberidion</i> p.p.)	No
H5130	<i>Juniperus communis</i> formations on heaths or calcareous grasslands	No
H6130	Calaminarian grasslands of the <i>Violetalia calaminariae</i>	Yes
H6150	Siliceous alpine and boreal grasslands	Yes
H6170	Alpine and subalpine calcareous grasslands	Yes
H6430	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels	Yes

4.4 Natural and semi-natural grassland formations

The impact of climate change on lowland meadows will depend on changes in rainfall and the interacting effects of water usage in the surrounding area. Currently lowland wet meadows are already under serious threat from drainage and with increased water stress and abstraction due to lower summer rainfall and warmer temperatures their condition is likely to deteriorate further. Low water tables are detrimental to important bird populations, which are already in serious decline in these habitats (Mitchell *et al.*, 2007).

Lowland plant species may be expected to spread into upland calcareous grasslands and recent results show that annuals and southerly distributed species are increasing on calcareous grasslands at the expense of more northerly species. The successful spread of flora northwards depends very much on the persistence and colonising ability of the species; management and land use are likely to have a greater effect on the distribution of these grasslands than climate change (Mitchell *et al.*, 2007).

Lowland dry acid grassland is thought to be fairly resilient to climate change with models showing little change or an increase in the suitable climate space for this habitat (Walmsley *et*

al., 2007). Limited soil nutrients may limit the response of the community to a longer growing season and increased temperature in upland areas. Changes in the relative abundance of grassland, heathland and bracken may also occur in this habitat as a result of climate change (Mitchell *et al.*, 2007).

Models predicting changes in climate space within upland hay meadows have shown a mixed response (Harrison *et al.*, 2001). Climate change is a threatening factor for grassland habitats which are at the northern edge of their range such as siliceous alpine and boreas grasslands in Scotland. Species abundances will change over time within habitats and sites, while species gains and losses may create new combinations of species or communities. Some modelling studies have indicated that a number of distinctive species of upland hay meadows, such as the wood cranes-bill (*Geranium sylvaticum*) and globeflower (*Trollius europeus*) may decline under climate change. There is observational evidence of an increase in species with a southern distribution within meadow communities (Mitchell *et al.*, 2007). Populations within mountain hay meadows may also be threatened by climate change such as rising temperature impacting on the *Geranium sylvaticum*'s ability to retain its bulky rhizome upon which it depends.

The distribution of dominant species such as sweet vernal grass (*Anthoxanthum odoratum*) and crested dog's tail (*Cynosurus cristatus*) is not predicted to change but wood cranes-bill (*Geranium sylvaticum*) may decline and thus, a distinctive characteristic species of upland hay meadows may eventually be lost. Globeflower (*Trollius europeus*) is also predicted to decline while greater burnet (*Sanguisorba officinalis*) may increase leading to a replacement of the currently characteristic plant communities of upland meadows with types similar to that found in the lowlands (Harrison *et al.*, 2001; Hopkins *et al.*, 2007). Observations of change show that northerly species in neutral grasslands are doing less well than southern species; in particular species typical of northern hay meadows such as smooth lady's mantle (*Alchemilla glabra*), intermediate lady's mantle (*Alchemilla xanthochlora*) and eyebright (*Euphrasia officinalis* agg.) have declined, with climate change suggested as one of the drivers of this change. This provides further evidence to support model predictions that the flora of northern upland hay meadows will change to one more similar to lowland hay meadows. (Mitchell *et al.*, 2007)

Calcareous grasslands (uplands and lowlands) are among the most species-rich plant communities in Europe (Hillier *et al.*, 1990) and the impact of climate change on this habitat is well studied compared to other habitats. Models predict a potential increase in the climatic envelope for calcareous grasslands (Walmsley *et al.*, 2007) although its spread is limited by geology, with most calcareous substrates occurring in southern England and the outcrops in the north fragmented. Similarly, while the climatic envelope for some calcicolous species may increase, the predicted change is relatively small when the constraints of soil suitability are considered. (Mitchell *et al.*, 2007)

The response of the calcareous grassland plant community to climate change appears to be related to the history of the grassland. Fertile or early successional calcareous grasslands composed of fast-growing or short-lived species are more likely to be affected by climate change than older calcareous grasslands. Deep-rooted herbs and short-lived ruderal species will increase on calcareous grasslands under drought, while grasses will only increase if rainfall increases which is unlikely. Therefore, the plant community composition of calcareous grasslands will change with an increase in herbs and ruderal species as the climate changes (Mitchell *et al.*, 2007). However, the prospects of lowland calcareous grasslands are difficult to define with some modelling suggesting that they have low sensitivity to climate

change while experimental research shows significant shifts in the botanical composition of the habitat. Temperature, rainfall and CO₂ levels have all been shown to affect the nitrogen dynamics of calcareous grasslands, but the results are complicated with the drivers interacting with each other (Mitchell *et al.*, 2007).

Purple moor grass and rush pastures are dominated by *Molinia* vegetation. *Molinia caerulea*-*Cirsium dissectum* fen meadow is especially vulnerable to changes in water-table and flooding, usually requiring the winter water-table more or less at the soil surface (very rarely with any inundation) and the summer water-table at 10-53cm below soils surface (mean *ca* 25cm). Changes in the distribution of rainfall, with wetter winters and drier summers, would be inimical to the survival of species-rich *Molinia* stands. Experimental and monitoring evidence shows that both raised water-levels and drainage can damage this community, resulting in a decline in the condition and possibly the extent of this habitat. (Mitchell *et al.*, 2007)

Table 4.4 Summary of possible impacts on specific Annex I habitats

Relevant Annex I habitats		Climate change likely to be a future threat to overall conservation status of habitat
Annex I habitat code	Feature name	
H2330	Inland dunes with open <i>Corynephorus</i> and <i>Agrostis</i> grasslands	No
H6210	Semi-natural dry grasslands and scrubland facies: on calcareous substrates (<i>Festuco-Brometalia</i>)	Yes
H6211	Semi-natural dry grasslands and scrubland facies: on calcareous substrates (<i>Festuco-Brometalia</i>) (important orchid sites)	Yes
		Yes
H6410	<i>Molinia</i> meadows on calcareous, peaty or clayey-silt-laden soils (<i>Molinion caeruleae</i>)	Yes
H6510	Lowland hay meadows (<i>Alopecurus pratensis</i> , <i>Sanguisorba officinalis</i>)	Yes
H6520	Mountain hay meadows	Yes

4.5 Raised bogs and mires and fens

There are substantial uncertainties in the impacts of climate change on the biodiversity of wetland and aquatic habitats. However as transitional habitats between terrestrial and aquatic situations wetlands are therefore vulnerable to perturbations in precipitation and temperature. The processes affected include water flows, carbon fluxes, nitrogen mineralisation and denitrification, precipitation, water temperatures, chemical quality, water stratification, oxygen supply, ground water recharge, flooding regimes and evaporation. All of these will have effects on biodiversity (Mitchell *et al.*, 2007).

There remains uncertainty in terms of the impact of large-scale climatic changes on UK wetland and aquatic ecosystems, especially with respect to the key role of climate as a controlling factor in determining ecosystem attributes (including composition). Climate change affects ecosystem dynamics, community productivity and composition, which in turn affect both the trophic structure of wetlands and their resource dynamics, with feedbacks to climate, the wetlands themselves and to associated habitats, as well as the ecotones between wetlands and other habitats (Mitchell *et al.*, 2007).

In parts of the country where summers become drier and winters wetter, there is likely to be a loss of peat and contraction of area of bogs. Where they dry out in summer, bogs are liable to invasion by trees which could locally lead to increased water loss through transpiration and higher heat absorption enhancing the drying effect on the bog surface. In some circumstances, wetter winters may offset the effects of drier summers (Mitchell *et al.*, 2007).

Peatlands in wet, oceanic areas are likely to remain relatively unchanged and models indicate little change in climate space for key blanket bog species such as hare's tail cotton grass (*Eriophorum vaginatum*) and bog-myrtle (*Myrica gale*). Cloudberry (*Rubus chamaemorus*) has, however, been identified as a species that is liable to change and south-western bog systems may gain species with more southerly distributions (Mitchell *et al.*, 2007). Highly fragmented habitats such as Alpine pioneer formations of the *Caricion bicoloris-atrofuscae* contain species which are at the limits of viability resulting in climate change being an important threat.

Temperate peatlands hold a quarter of all soil carbon, illustrating their importance as a global sink. But they can act as source or sink depending on delicate balance of climate, water supply, and temperature (Mitchell *et al.*, 2007). Precipitation patterns, both temporal and spatial, are the key variable in determining the impact of global warming on the carbon budget of bogs and other mires (Mitchell *et al.*, 2007). A large proportion of the carbon stored in UK soils and vegetation is within protected areas and other high-quality wildlife sites, especially in peatlands, and its management is a significant responsibility for land managers. There has, however, been very little quantification of the way in which conservation management practices impact upon carbon in the soil and vegetation. Such knowledge is urgently needed in order to ensure that they do not result in the increased release of greenhouse gases and, where possible, do result in carbon being removed from the atmosphere (Hopkins *et al.*, 2007).

In the British situation, the possible "risks" to fen, marsh and swamp under predicted climate change are (from Mitchell *et al.*, 2007):

- Change in species composition to favour temperature responsive species.
- Increased risk of soligenous fens drying out in summer.
- Drought may exacerbate damage to plant species from atmospheric pollution.
- Increased pollution risk from runoff from surrounding agricultural land.

The main factors affecting water and wetlands that will be altered by climate change (from Mitchell *et al.*, 2007) are:

- Carbon fluxes - CO₂ and methane.
- Nitrogen mineralisation and denitrification.
- Precipitation patterns – amounts, seasonality and spatial distribution.
- River flows – quantity, timing, duration, frequency and quality, including physical quality (e.g. temperature) and chemical quality (e.g. pH, suspended sediment load).

- Water supply mechanisms to wetlands e.g. impacts on groundwater recharge, flooding regimes and evaporation.
- Biological patterns of activity and the flora/faunal composition of the habitats themselves and those associated with and affecting water bodies and wetlands.
- Stratification of deeper water bodies and oxygen supply.
- Primary productivity of aquatic algae in lakes.
- Altered demand by human populations for water abstraction and land drainage.

Table 4.5 Summary of possible impacts on specific Annex I habitats

Relevant Annex I habitats		Climate change likely to be a future threat to overall conservation status of habitat
Annex I habitat code	Feature name	
H7110	Active raised bogs	Yes
H7120	Degraded raised bogs still capable of natural regeneration	Yes
		Yes
H7140	Transition mires and quaking bogs	Yes
H7150	Depressions on peat substrates of the <i>Rhynchosporion</i>	Yes
H7210	Calcareous fens with <i>Cladium mariscus</i> and species of the <i>Caricion davallianae</i>	Yes

4.6 Forests

The broad habitat (broadleaved, mixed and yew woodland) will persist under climate change but species composition and distribution may change. Drought, like temperature, is more likely to cause an adjustment of species composition and dominance rather than outright loss of woodland. Drought is likely to be the most serious threat, with a number of tree species, particularly beech, birch and sycamore, drought-sensitive. However, it is not expected that woodlands will become completely different habitats: even where sensitive tree species such as birch, beech or sycamore die, other tree species would be expected to replace them. A greater risk of forest fire is also associated with more frequent summer droughts. The threat to beech trees threatens the long-term health of the lowland beech and yew woodland priority habitat in the south and east, although localised soil conditions (particularly chalk geology) and microclimates may continue to support the habitat (Mitchell *et al.*, 2007). Sea level rise is not a serious threat to the large majority of British woodlands, although it may be locally important (Mitchell *et al.*, 2007).

There has been a general trend towards spring and summer events taking place earlier in the year. These include earlier first leafing dates of trees (e.g. oak leafing has advanced three weeks in the last 50 years). Autumn events are more complex, with delayed leaf fall also evident (Hopkins *et al.*, 2007). There is also the potential for adverse outcomes from complex interactions such as a breaking of synchrony between different trophic levels. Changes in phenology can be most confidently related to recent climate change. There is a strong relationship between temperature and date of budburst and flowering in many tree, shrub and ground flora species and a significant trend towards earlier phenology in recent decades (Mitchell *et al.*, 2007).

European forests have increased their above-ground biomass; and this is thought to be due to a combination of factors including climate change, increased carbon dioxide in the atmosphere and greater nitrogen deposition (Hopkins *et al.*, 2007)

The impacts of climate change on woodlands are diverse. There is evidence of impacts related to rainfall; temperature; windspeed; interactions with other factors resulting in (from Mitchell *et al.*, 2007):

- *Changes in phenology*: such as changes in leafing dates of trees (budburst) with consequences for ground flora, competitive advantages of some species and potential for loss of synchrony between flowers and pollinators and predators and prey (e.g. pied flycatcher and caterpillars).
- *Changes in distribution*: will be limited among woodland trees although summer drought may lead to loss of species such as Beech in southern England.
- *Changes in community structure*: such as a switch in dominant species largely due to differences in drought tolerances and enhanced recruitment of species favoured by warmer temperatures.
- *Changes in ecosystem function*: loss of woodland would, for example, increase risk of soil erosion in some areas.
- *Loss of physical space due to sea level rise and increased storminess*: only about 1% of woodland resource appears threatened by tidal inundation (Mitchell *et al.*, 2007).

Table 4.6 Summary of possible impacts on specific Annex I habitats

Relevant Annex I habitats		Climate change likely to be a future threat to overall conservation status of habitat?
Annex I habitat code	Feature name	
H9120	Atlantic acidophilous beech forests with <i>Ilex</i> and sometimes also <i>Taxus</i> in the shrublayer (<i>Quercion robur-petraeae</i> or <i>Ilici-Fagenion</i>)	No
H9130	<i>Asperulo-Fagetum</i> beech forests	No
H9160	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the <i>Carpinion betuli</i>	Yes
H9180	<i>Tilio-Acerion</i> forests of slopes, screes and ravines	No
H9190	Old acidophilous oak woods with <i>Quercus robur</i> on sandy plains	No
H91A0	Old sessile oak woods with <i>Ilex</i> and <i>Blechnum</i> in the British Isles	Yes
H91C0	Caledonian forest	No
H91D0	Bog woodland	Yes
H91E0	Alluvial forests with <i>Alnus glutinosa</i> and <i>Fraxinus excelsior</i> (<i>Alno-Padion</i> , <i>Alnion incanae</i> , <i>Salicion albae</i>)	Yes
H91J0	<i>Taxus baccata</i> woods of the British Isles	No

5. Possible impacts of climate change on Species Favourable Conservation Status Features

Species are increasing and decreasing their abundance at sites in ways correlated to climate change. This has been shown by long-term monitoring of butterflies and moths, and plants in woodlands and grasslands, changing the composition of plant and animal communities (Hopkins *et al.*, 2007).

5.1 Invertebrate species: molluscs

Changes in rainfall and temperature have been shown to affect invertebrates found on calcareous grasslands, e.g. leafhoppers and molluscs. A movement northwards and eastwards of many benthic marine organisms is also expected, particularly those near the geographic limits of their distribution and has already been observed in some intertidal species. Northern species are getting rarer (e.g. *Semibalanus balanoides* and *Patella vulgata*); these are often faster growing and more productive than southern species. A rapid spread in introduced bivalves such as Pacific oysters (*Crassostrea gigas*) is also occurring. Indeed, increasing temperatures due to climate change are thought to be an important factor in facilitating the arrival and establishment of non-native species (Mitchell *et al.*, 2007).

5.2 Invertebrate species: arthropods

The phenology of invertebrates is particularly sensitive to climatic changes. There are likely to be winners and losers amongst the invertebrates, with northern species and those of wet places tending to decline (Walmsley *et al.*, 2007). There has been a general trend towards spring and summer events taking place earlier in the year for example flight times of moths and butterflies, and first appearance of hoverflies (Hopkins *et al.*, 2007). There is also increasing evidence of non-migratory species which reach the northern limit of their distribution in the UK expanding their range northwards and on to higher ground, including birds, butterflies, dragonflies and damselflies, aquatic bugs, soldier beetles, longhorn beetles, millipedes, harvestmen, ground beetles, woodlice, mammals, fish, spiders, lacewings and grasshoppers and crickets (Hopkins *et al.*, 2007).

Of greatest importance may be that interdependent species no longer have life cycles that are synchronised. There is for example good evidence that some populations of the pied flycatcher (*Ficedula hypoleuca*) are declining because birds are now breeding after the time of peak caterpillar abundance, which has become earlier (Hopkins *et al.*, 2007). Butterfly species which over-winter as eggs and larvae are being excluded from grasslands, due to rapid plant growth early in the year which, paradoxically, creates a cooler spring microclimate in the sward (Hopkins *et al.*, 2007).

Many species of conservation concern are often separated by large distances that exceed their normal dispersal capabilities from other patches of suitable habitat. For example, some butterfly species are increasing in local abundance but not increasing their range (Hopkins *et al.*, 2007). Invertebrate species of continental Europe are likely to colonise and increase in frequency. (Mitchell *et al.*, 2007). However, suitable habitats for species such as the Stag beetle, which requires dead wood and tree stumps for larval development, are likely to persist under climate change, though the dispersal ability of individuals may limit widespread displacement (Walmsley *et al.*, 2007).

5.3 Vertebrate species: fish

The distribution of fish species has changed in recent decades – one study showed nearly two thirds of species has shifted mean latitude, depth or both in 25 years. Population fluctuations in fish have also been shown to be sensitive to climate. (Mitchell *et al.*, 2007). Other groups of animals showing distribution change include benthic species and phytoplankton. There has also been an increase in the number of alien species. Changes in phenology in coastal and marine systems can also lead to the mistiming of biological events (Mitchell *et al.*, 2007)

5.4 Vertebrate species: amphibians

There is a trend towards spring and summer events taking place earlier in the year including first spawning of amphibians (Hopkins *et al.*, 2007). There is evidence of the temperature sensitivity of phenology in toad populations, where high temperatures advance most events in the spring breeding period. The emergence of adult mayflies is also climate sensitive (Mitchell *et al.*, 2007). Rare amphibian and reptile species are not showing a northward movement of their range as might be expected of southern species at the northern edge of their range in the UK (Hopkins *et al.*, 2007).

5.5 Vertebrate species: mammals

Bats have a number of features which place them at risk of environmental change, including their slow breeding rate and their aggregation in large colonies. The greater and lesser horseshoe bats are at the northern and western climatic edge of their distribution in the UK. Their distribution covers north-western Africa, Mediterranean Europe across to Pakistan. Under warmer climatic conditions such species are expected to expand northerly in the UK. However their ability to expand will be limited by the indirect impacts such as availability of roost sites, feeding habitat and hibernation sites (Walmsley *et al.*, 2007). The Barbastelle bat is a rare woodland species found in southern England and Wales. The capacity of this bat to expand into new areas may be limited by suitable roost and hibernation sites rather than feeding grounds. It is known to make long flights (290km) and is likely to have a dispersal capacity to extend its range under a changed climate. However, like the greater and lesser horseshoe bats the potential impacts of climate change remains unknown (Walmsley *et al.*, 2007). Warmer, wetter winters are likely to result in a reduced hibernation period for bats with reduced reliance on underground sites (Defra, 2005).

Marine mammals are likely to be impacted on by changes in the physical, biological and biogeochemical characteristics of oceans and coasts. The complexity of ocean processes and climate varies greatly across areas. Habitat preferences of marine mammals, such as dolphins, porpoises, seals and otters, are often defined by physical and chemical characteristics of the water which defines water masses and current boundaries where prey accumulates (Defra, 2005). Potential direct effects of changes in water temperature are shifts in species range while the indirect effects prey species include changes in distribution, abundance, community structure, susceptibility to disease and reproductive success. Changes in ocean currents will also have profound impacts on the distribution, abundance and migration of plankton, fish and cephalopod species which in turn will affect marine mammals (Defra, 2005).

5.6 Higher plant species

MONARCH examined the potential climate space under different climatic scenarios for the floating water plantain. The species has a very limited range, which combined with a scattered record throughout the UK renders models limited use. Management of nutrient inputs to habitat sites will be important as the species has declined due to eutrophication in the past and reducing other stressors will be important for minimising climatic impacts (Walmsley *et al.*, 2007).

ANNEX 1 – Summary of direct impacts of climate change on habitats, ecosystem functioning and species in England

These tables are adapted from ‘**England Biodiversity Strategy - Towards Adaptation**⁷’ which was published in May 2007. Whilst the geographical focus is primarily England, much of the evidence and resources used to inform the publication are UK-wide. The general effects of climate change on biodiversity identified here are therefore likely to be valid across the UK, however there will be regional and localised impacts of climate change in Wales, Scotland and Northern Ireland which are not accounted for. In particular, species and habitats at the edge of their boundary will not be well represented in this case, for example montane species and habitats in Wales and northernmost species and habitats in Scotland.

Summary of the direct effects of climate change on habitats (adapted from Mitchell *et al.*, 2007)

	Increased summer temperature	Increased winter temperature	Earlier spring	Summer drought	Wetter winters	Sea level rise	Increased flooding	Increased frequency of extreme events	Increased CO ₂ concentrations
Arable field margin	Arable field margins are quite resilient to change, but species found in these boundary habitats have recently been shown to be increasing. They respond to hot and dry conditions where more bare ground is opened for colonisation. Continental species may increase.		Changes in seasonal farm practices, loss of synchronicity could result in loss of species.	Changes in soil microbial activity, with effects on nutrient availability and consequences for flora.	Changes in soil microbial activity, with effects on nutrient availability and consequences for flora.	57% of Grade 1 agriculture land in the UK lies below the 5m contour leaving it subject to flooding, inundation, erosion and salinisation of fresh water, so large changes in land use could result.			
Species rich hedgerow	Invertebrate diversity may increase as more species colonise from continental Europe, but these could displace native species.			May cause increased death of hedgerow trees, particularly beech trees.					

⁷ <http://www.defra.gov.uk/wildlife-countryside/resprog/findings/ebs-climate-change.pdf> Second Report by the United Kingdom under Article 17 on the implementation of the Directive from January 2004 to December 2006

	Increased summer temperature	Increased winter temperature	Earlier spring	Summer drought	Wetter winters	Sea level rise	Increased flooding	Increased frequency of extreme events	Increased CO ₂ concentrations
Grasslands	<p>Upland hay meadows will lose northerly distributed species and southerly distributed species will spread northwards. Characteristic upland hay meadow species will be lost with a transition to a more lowland hay meadow community type. Fertile or early successional calcareous grasslands composed of fast-growing or short-lived species are more likely to be affected by climate change than older calcareous grasslands.</p>		<p>Decrease in the number of species occurring on calcareous grassland as vernal species are out competed.</p>	<p>Lowland meadows: change in crop and harvesting, from silage to hay, loss of species, including wetland birds which are associated with the wet substrate. Calcareous grassland: Deep rooted and short-lived ruderal species increase under drought, changes in rainfall and temperature have been shown to affect the invertebrates found on calcareous grasslands, e.g. leafhoppers and molluscs, N mineralisation rates will increase. Summer drought will increase N mineralisation rates, but additional summer rainfall will reduce N mineralisation in autumn and winter.</p>	<p>Increase in water meadows to manage flood waters. In calcareous grassland grasses dominate under increased rainfall. <i>Molinia caerulea-Cirsium dissectum</i> fen meadow is intolerant of lowering ground water in summer or flooding in winter.</p>		<p>Increase in water meadows to manage flood waters.</p>		

	Increased summer temperature	Increased winter temperature	Earlier spring	Summer drought	Wetter winters	Sea level rise	Increased flooding	Increased frequency of extreme events	Increased CO ₂ concentrations
Heathland	Wet heaths and peatlands may be more sensitive to climate change than dry heaths, with these habitats declining in area. Increased in generalist species in upland heath communities causing increased diversity, but a shift in upland community composition. Warmer conditions result in increased soil nitrogen levels favouring grass growth. Increased risk of fire.			Shift in lowland heathland communities, changes in ratio of grassland/ heathland/ bracken. Heather may be favoured over bracken. Dry acid grassland may spread at expense of heather. Spread of dwarf gorse northwards and westwards, perhaps replacing western gorse. Changes in soil microbial activity and nutrient cycling. On wetter sites drought increases microbial activity.	On drier sites, drought decreases microbial activity.			Loss of heathland through fires.	
Montane	Loss of montane heath.			Mountain top species are most at risk from climate change as they have nowhere to retreat to as the climate changes. Rare, isolated and habitat specialists may be lost.					

	Increased summer temperature	Increased winter temperature	Earlier spring	Summer drought	Wetter winters	Sea level rise	Increased flooding	Increased frequency of extreme events	Increased CO₂ concentrations
Freshwater wetland	Groundwater-fed wetlands more resilient to temperature change than ombrotrophic sites. Accelerated transition to terrestrial habitats, partly through increased evapo-transpiration. Change in species composition toward more continental and/or southern species. In combination with higher CO ₂ levels, increased productivity and changes in grazing preference of some invertebrates.	Some continued evapo-transpiration. Survival of more pathogens.	Phenology: altered breeding/flowering times. Loss of synchronicity resulting in disrupted ecosystem function.	Closely linked to increased summer temperature. Changes in soil microbial activity, with effects on nutrient availability and consequences for flora.	More prolonged waterlogging resulting in altered community composition. Need to increase flood-storage through constructed wetlands.	Coastal freshwater and brackish wetlands subject to flooding and salinisation.	Increase in constructed wetlands (water meadows, Great Fen., etc.) in order to manage flood waters.	Impacts on species recruitment and community regeneration.	

	Increased summer temperature	Increased winter temperature	Earlier spring	Summer drought	Wetter winters	Sea level rise	Increased flooding	Increased frequency of extreme events	Increased CO ₂ concentrations
Peatlands (bogs and fens)	Loss of peat through aerobic decomposition – increased loss of CO ₂ and release of NO _x . Soligenous mires may dry out in summer (via rise in evapotranspiration, <i>etc</i>) with trees colonising. Reduction in circumpolar boreal-montane species. Variable responses in mire plant communities, with disruption in composition and structure. Increase in density of Enchytraeid worms. Increased incidence of fires.	Reduction in extent of boreal bryophytes, <i>etc</i> .		Increased aerobic decomposition - loss of CO ₂ and release of NO _x to atmosphere. Contraction of bogs in south and east (more secure in north and west with increased precipitation).		Few peatlands survive in the coastal zone, but those that do (Broads, Somerset, Moors, etc) vulnerable.	Reversion from fens to swamps, and tendency for bogs to lose obligate calcifuge species as ombrotrophic regime disrupted.	Loss of mires through fire or flooding.	

	Increased summer temperature	Increased winter temperature	Earlier spring	Summer drought	Wetter winters	Sea level rise	Increased flooding	Increased frequency of extreme events	Increased CO ₂ concentrations
Floodplain wetlands	Incidence of flooding similar to current or reduced. Geographical changes in waterfowl breeding. Raised productivity of wetlands.	Geographical change in waterfowl wintering.	Decrease in the number of strictly vernal species in floodplain grassland due to competition from productive grasses.	Change in lowland wet grassland types from MG8 to MG5 <i>etc.</i> Changes from hay to silage and loss of obligate wetland species. N mineralisation rates will increase.	Altered a) timing of sediment input from floods, b) provision of fish spawning sites; and c) protection of sward from frost. Increase in constructed water meadows to manage flood waters. Grasses increasingly dominant.	Change from freshwater swards (MG5, MG8, MG9, MG10, <i>etc.</i>) to those tolerant of brackish conditions (MG11, MG12, <i>etc.</i>).	Duration and incidence will determine community through waterlogging. Accumulation of CO ₂ , methane and nitrogen during flood, with subsequent release. Altered thermal conditions. Changed soil structure. Increased areas for water-fowl breeding/roosting. Death of soil invertebrates. Replace soil fungi by bacteria, reducing decomposition rates. Reduced redox potential and rise in pH.	Communities dependent on regular moderate flooding disrupted.	

	Increased summer temperature	Increased winter temperature	Earlier spring	Summer drought	Wetter winters	Sea level rise	Increased flooding	Increased frequency of extreme events	Increased CO ₂ concentrations
Lakes, pools and other still waters	Water tends to buffer effect of raised temperature. Primary productivity raised with consequent impact on higher trophic levels and reduced light penetration. May favour <i>Cyanobacteria</i> within phytoplankton. Destabilise macrophyte-dominated lakes. Benefit invasion of species with currently eastern distribution. Disrupted stratification of lakes <i>etc.</i>	Reduced duration and extent of ice cover. Higher levels of phytoplankton and earlier breeding of some species.	Increased densities of aquatic invertebrate grazers. Altered breeding of <i>Amphibia</i> , and emergence of mayflies, <i>etc.</i>	Encroachment of marginal emergent vegetation zone. Shallow water-bodies may become only seasonally wet and transient.	Flooding higher up shoreline, displacing the drawdown zone.	As freshwater wetlands and peatlands – some Broads vulnerable. Increased incidence of brackish lagoons.	Similar impact to wetter winters.	Loss of species with narrow ecological amplitude.	
Rivers	Water tends to buffer effect of raised temperature. Decreased river flow with critical values for biota exceeded and loss of habitat. Reduced suitability for Salmonid breeding.	Increased river flow, tempered by increased evaporation.	Change in the seasonal timing of peak flows.	Chronic low flows with risk of deoxygenation and disrupted connectivity along river. Loss of instream physical habitat.	Generally higher winter flows – but possibly with somewhat smaller flow peaks following melt of smaller quantities of snow.	Alteration in estuarine ecotone and sedimentation patterns.	Increased erosion and sediment load with impacts on fish suitability.	Rapid changes in channel morphology following flash floods.	

	Increased summer temperature	Increased winter temperature	Earlier spring	Summer drought	Wetter winters	Sea level rise	Increased flooding	Increased frequency of extreme events	Increased CO₂ concentrations
Broad-leaf mixed and Yew woodland	Potential introduction of new pest species from warmer climates may present threat to tree species and hence change character of habitat.	Increased threat to tree species from pests and diseases over-wintering where they would not previously have done so.		Increased mortality of drought sensitive species, e.g. beech, birch and sycamore especially in South East. This would be expected to lead to their proportional decrease within woodlands and so a change in the nature of the habitat. However, drought sensitive species are still expected to persist, particularly on more favourable geologies (e.g. chalk) and microclimates (e.g. north-facing slopes).		Potential loss of low-lying coastal woodlands.	Wet woodland may expand as a result of planting or abandonment of particularly flood prone agricultural areas.	An increase in windthrow is likely, leading to an increase in gaps in woodland and deadwood. Increased risk of forest fire destroying habitat.	

	Increased summer temperature	Increased winter temperature	Earlier spring	Summer drought	Wetter winters	Sea level rise	Increased flooding	Increased frequency of extreme events	Increased CO ₂ concentrations
Coniferous woodland	Potential introduction of new pest species from warmer climates may present threat to tree species and hence change character of habitat.	Increased threat to tree species from pests and diseases over-wintering where they would not previously have done so.		More drought resistant species, such as Douglas Fir and Corsican pine grow better than, for example Sitka Spruce. The outcome is likely to be their planting over a wider area in England but this will depend on management decisions, taking account of other issues in addition to direct climate effects, for example Corsican pine is unlikely to be planted more widely because of its susceptibility to red band needle blight (<i>Dothistroma pini</i>).		Potential loss of low-lying coastal woodlands.		An increase in windthrow is likely, leading to an increase in gaps in woodland and deadwood.	
Salt marsh and/or coastal grassland	Increased evaporation may lead to drying up of coastal grazing marsh.	No major changes documented, but north-easterly shift in associated species likely.	Earlier onset of breeding. Possible phenotypic mistiming with invertebrate prey.	Drying up of coastal grazing marsh.	Flooding of coastal grazing marshes.	Inundation of coastal grazing marsh and salt marsh. Loss of the latter predicted to be as much as 10,000 ha by 2013.	More variable water-levels resulting in increased stress on many plant species and potential flooding of bird nests.	Increased erosion.	Decreased abundance of calcifying organisms.
Estuaries	Northward shift in inter-tidal organisms.	Increased proportion of UK over-wintering population of waders over-wintering on east coast estuaries.	Phenological advancement likely.	Higher nutrient levels and lower oxygen levels anticipated.	Lower salinity expected.	Change in morphology. In general large mudflats are expected to become sandier.	Periodic influx of freshwater with poorly documented consequences.	Morphological changes.	Decreased abundance of calcifying organisms.
Saline lagoons	Increased evaporation will lead to hypersaline conditions in summer.		Some phenological advancement likely.	Lower rainfall will lead to hypersaline conditions in summer.	Increased freshwater input likely to lead to low-saline conditions in winter.	Increased saltwater input during the winter will lead to changes in salinity regimes.	Periodic influx of freshwater, leading to more variable salinity conditions.	Increased flooding with saltwater.	

	Increased summer temperature	Increased winter temperature	Earlier spring	Summer drought	Wetter winters	Sea level rise	Increased flooding	Increased frequency of extreme events	Increased CO2 concentrations
Open seas	Major changes in phytoplankton community with knock-on effects for species at higher trophic levels. Increased occurrence of sub-tropical species.	Increased occurrence of species associated with lower latitudes.	Earlier hatching and faster embryonic development and growth of marine organisms.			Slight landward movement of benthic organisms possible.		Changes in dispersal patterns of pelagic organisms likely.	Decreased abundance of calcifying organisms and species with pH sensitive blood.
Other coasts and seas	Northward shift of benthic marine organisms on rocky shores.	North-easterly shift of benthic marine organisms on rocky shores.	Earlier arrival of migratory species anticipated.	Less fucoids likely on rocky shores.	Increased erosion of coastal cliffs.	Increased erosion of coastal cliffs, sand dunes and other habitats.	Increased erosion of coastal cliffs.	Increased erosion of coastal cliffs.	Reduction in growth rate of scleractinian corals.

Summary of the direct effects of climate change on ecosystem function and species (adapted from Mitchell *et al.*, 2007)

	Increased summer temperature	Increased winter temperature	Earlier spring	Increased summer drought	Wetter winters	Increased flooding / sea level rise	Increased frequency of extreme events	Changes in upwelling zones and increased stratification	Increased CO₂ concentrations
Agriculture Ecosystem function	Lengthen the growing season for plants. For each 1°C increase in temperature the growing season can increase by approximately three weeks in South East England and by about ten days in northern areas, resulting in thermal growing conditions extending year round in Southwest England later this century.	Disruption of normal over-wintering patterns.	The first swallow, hawthorn in flower, beech tree leafing, spring barley showing awn and apple buds opening were all happening significantly earlier between 1990-2000 than in 1980-1990. There could be adverse effects on other species due to loss of synchronicity of life cycle events and resource availability.	Soil moisture is predicted to decline by 20-50% in South East England in the summer by 2050, this will affect soil micro-organisms, crops and also the survival of arable weeds.	Winter rainfall and flooding may increase soil moisture, changing microbial activity, nutrient cycling and associated species. Change in soil moisture will also affect agricultural practices and the type of crops grown, with consequences on resources available and currently exploited by species. Could stimulate fungal pathogens.				
Agriculture Species	Longer growing seasons will result in more life cycles of pests e.g. aphids and arable weeds within a season and greater risk of pesticide and herbicide application. A warmer more continental climate may benefit many of the rare arable plant species associated with arable fields, provided that agricultural practices allow their establishment and spread.	Pests and diseases may survive the winter and increase, this may put pressure on other native species, directly or through increased use of pesticides.	Blight may appear earlier.						

	Increased summer temperature	Increased winter temperature	Earlier spring	Increased summer drought	Wetter winters	Increased flooding / sea level rise	Increased frequency of extreme events	Changes in upwelling zones and increased stratification	Increased CO₂ concentrations
Water and wetlands Ecosystem function	All changes will have most marked impact in ecotonal habitats, altering their distribution, width and composition. Changes in the growing season for plants (see agricultural sector, Section 3.1) and hence on productivity and energy fluxes. Effects on bacterial activity and nutrient cycling, including carbon fluxes (notably within peatlands) and patterns of nitrogen mineralisation and denitrification. Altered evapotranspiration. Reduced water availability and quality.	Disruption of stratification (thermocline and nutrients). Altered evapotranspiration.	Differential responses may result in a disruption of the connectedness among species in current ecosystems.	As well as impacts on soil micro-organisms, plants and animals (see agriculture sector, Section 3.1), marked changes in river flow regime disrupting functional connectivity between source and mouth and between channel and floodplain. Reduced summer groundwater recharge (but variation between south and north) 20% less annual runoff in south and east (25% higher in northeast) with altered seasonal distribution.	Winter rainfall and flooding may increase soil moisture, changing microbial activity, nutrient cycling and associated species supported. Increased groundwater recharge.				
Water and wetlands Species	Impacts on organisms with narrow tolerance ranges. Changes in growth rates of organisms. Conditions more favourable for species of currently southern, eastern and Continental distributions.	Decline in species of boreal and circumpolar distribution. Changes in migration patterns of wintering birds. Altered survival of wetland invertebrates.	Individual species displaying different responses – hence ecosystem response.	Reduced vigour and/or death of hydrophytes and helophytes. Reduced feeding opportunities for wetland animals, resulting in reduced breeding success.	Changes in feeding opportunities for wintering animals. Duration of wet conditions affecting competitive interactions during spring and hence community composition.				

	Increased summer temperature	Increased winter temperature	Earlier spring	Increased summer drought	Wetter winters	Increased flooding / sea level rise	Increased frequency of extreme events	Changes in upwelling zones and increased stratification	Increased CO₂ concentrations
Woodland Ecosystem function	Potential increase in productivity (and carbon sequestration), but likely to be outweighed by reductions in summer rainfall, at least in the south east.	Increase in soil respiration would tend to increase release of carbon dioxide from soils.	Earlier leafing and flowering. Longer growing season likely to increase productivity and carbon sequestration in north and west but may be outweighed by drought in the south east. Some evidence for disruption of synchrony between species at different trophic levels (for example bird-caterpillar-tree food chains) and between pollinators and flowers.	Decrease in productivity and carbon sequestration especially in south and east.	May partially offset effects of drier summers by increasing ground water levels at the start of the summer.	Limited evidence that floodplain woodlands may reduce impact of flood events.			
Woodland Species	Colonisation of invertebrate species from southern Europe, may enrich biodiversity. Southern species may extend northwards (e.g. speckled wood butterfly).	Species currently limited by low winter temperatures may extend their range.	Decrease in populations of drought sensitive species – both of trees and other types of organism. e.g. speckled wood butterfly.				Increased dead wood as a result of windthrow would be expected to lead to an increase in deadwood specialist species, assuming dead wood is left in situ. An increase in the number of gaps would stimulate regeneration and favour woodland edge and other moderately light demanding species.		

	Increased summer temperature	Increased winter temperature	Earlier spring	Increased summer drought	Wetter winters	Increased flooding / sea level rise	Increased frequency of extreme events	Changes in upwelling zones and increased stratification	Increased CO ₂ concentrations
Coastal and seas Ecosystem function	Longer growing season for plants may result in net increase in primary productivity. Variable advancement in phenology likely to change ways in which species interact. Major changes in marine phytoplankton communities will significantly alter the species composition and functioning of marine habitats.	Variable north-easterly changes in the distribution of organisms are likely to affect the ways in which species interact.	Variable advancement in phenology likely to change ways in which species interact.	Changes in nutrient cycling, community composition and productivity of coastal grazing marsh anticipated.	Changes in nutrient cycling, community composition and productivity of coastal grazing marsh anticipated.	Reduction in organic input to estuarine habitats, due to loss of salt marsh likely to have a major impact on food webs.	Loss of seal haul out sites.	Increased ocean stratification likely to have a major impact on the functioning of marine habitats, with catastrophic reduction in the productivity of surface water.	Increased acidity of marine habitats likely to result in changes in community composition, with declines in calcifying organisms and those species that prey on them expected.
Coastal and seas Species	Northward range extension of benthic and intertidal organisms and fish. Increase in mean depth of fish. Increased occurrence of sub-tropical species such as anchovy (<i>Engraulis encrasicolus</i>), sardine (<i>Sardina pilchardus</i>) and leatherback turtle (<i>Dermochelys coriacea</i>). Rapid spread of non-native bivalves such as Pacific Oyster (<i>Crassostrea gigas</i>).	North-easterly range extension of non-estuarine waders. Higher proportion of estuarine waders overwintering on the east coast.	Earlier hatching and faster embryonic development and growth of squid. Earlier egg-laying of waders.		Higher stress for species associated with saline and brackish lagoons due to more variable salinity regimes.			Large declines in apex predators such as seabirds.	Reduction in abundance and growth of calcifying organisms. Increased mortality of pH sensitive species such as squid.