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England Biodiversity Strategy- Towards adaptation to climate change

Final Report to Defra for contract CR0327

May 2007

R.J. Mitchell¹, M.D. Morecroft¹, M. Acreman¹, H.Q.P. Crick², M. Frost³, M. Harley⁴, I.M.D. Maclean², O. Mountford¹, J. Piper⁵, H. Pontier⁶, M.M. Rehfisch², L.C. Ross¹, R. J. Smithers⁷, A. Stott⁶, C. Walmsley⁸, O. Watts⁹, E. Wilson⁵.

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England biodiversity strategy – towards adaptation to climate change.

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¹The Centre for Ecology and Hydrology

²The British Trust for Ornithology

³The Marine Biological Association

⁴Natural England

⁵Oxford Brookes University

⁶Department for Environment, Food and Rural Affairs

⁷The Woodland Trust

⁸Countryside Council for Wales

⁹Royal Society for the Protection of Birds

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1. The evidence that the Earth's climate is changing as a consequence of human activity is strong and accepted by the overwhelming majority of scientific opinion. The changing climate is beginning to have an impact on English ecosystems and this impact is expected to increase and accelerate in future, threatening the conservation of biodiversity.

2. The England Biodiversity Strategy (EBS) "Working with the Grain of Nature" aims to ensure that biodiversity considerations become embedded in all the main sectors of economic activity that have an impact on or relationship with delivery of biodiversity objectives, both public and private.

3. This report reviews the scientific evidence and summarises the potential impacts of climate change on the biodiversity of England within each of the sectors of the EBS: Agriculture, Water and Wetlands, Woodland and Forestry, Coastal and Marine, Towns and Cities. It includes direct impacts and indirect ones resulting from human responses to climate change. It gives a brief overview of the main non-climatic pressures on biodiversity and their possible interactions with climate change. Principles and measures for adapting biodiversity policy and management to climate change are presented.

Climate

4. The best available estimates for England are for a warming of 1.5-2.5°C by 2050 and a change in the distribution of precipitation through the year. Precipitation in the South East is predicted to decrease by 30-40% in summer and increase by 15-20% in the winter. Models predict a sea level rise of up to 36cm over the same period.

Direct Impacts of Climate Change on Biodiversity:

5. Rising temperatures, changing rainfall patterns and other aspects of climate change are starting to have an impact on biodiversity in England and globally.

6. This report reviews a large number of scientific papers and the evidence is that impacts of climate change on biodiversity will become increasingly apparent across all EBS sectors. These changes present a threat to biodiversity conservation although there may also be some positive impacts.

7. Changes can be summarised into the following categories:

- Changes in phenology, which may lead to loss of synchrony between species
- Changes in species distribution (including arrival of non-native species and potentially loss of species for which suitable climate conditions disappear).
- Changes in community composition
- Changes in ecosystem function
- Loss of physical space due to sea level rise and increased storminess

8. Of the 32 priority habitats in the UK Biodiversity Action Plan, seven were assessed to be at high risk from the direct impacts of climate change, based on good to moderate evidence;

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montane habitats, standing waters, floodplain and grazing marsh, saltmarsh, maritime cliffs and slopes, saline lagoons and open seas. Five of these are within the Coastal and Marine sector. A further 14 were assessed to be at medium risk and 11 at comparatively low risk or medium low risk. However, the evidence base was rated as 'poor' for 12 priority habitats.

Indirect Impacts of Climate Change on Biodiversity

9. As the climate changes there will be changes in socio-economic drivers, working practices, policies and resource use within each of the EBS sectors. These changes could lead to both opportunities and threats for biodiversity conservation; although there are large uncertainties in anticipating exactly what changes will occur.

10. Agriculture responds rapidly to changes of policy, market forces and innovations in management and technology. Changes in crop types, regional patterns of crop planting, the introduction of carbon management initiatives, biomass and bio-fuel crops all have important implications for biodiversity but in many circumstances may be positive or negative depending on specific management decisions. Agri-environment schemes potentially provide opportunities for targeted action to protect and enhance biodiversity.

11. Biodiversity in habitats associated with the Water and Wetlands EBS sector will be affected by water resource issues and catchment management. Increased water abstraction and fragmentation by artificial structures such as impoundments, flood control and hydro-electric schemes are potential threats to biodiversity. The creation of wetland habitats for water storage and flood control and the introduction of integrated catchment management may offer opportunities.

12. Threats to biodiversity within the Woodland and Forestry sector may result from increasing emphasis on carbon sequestration or production of biomass for renewable energy generation. These drivers could promote more intensive management systems or tree planting on semi-natural habitats. Opportunities may however arise from woodland planting on biodiversity poor sites and the consequent creation of ecological networks. In some circumstances more intensive management may increase habitat diversity in woodlands

13. Within Towns and Cities, negative impacts on biodiversity may result from the intensification of land use as a consequence of policies for increasing energy efficiency. Strategic planning for sustainable development may offer opportunities to incorporate biodiversity objectives; biodiversity can be included within new designs for building and open spaces and wetland habitats may be created as part of flood management and sustainable urban drainage systems.

14. Within the Coasts and Seas sector, fisheries policy has a major impact on biodiversity. Policy in the coastal zone could have positive or negative effects, depending on whether habitats are created by managed realignment and the nature of coastal defences. Increased tourism development and renewable energy schemes also have the potential for negative impacts in some circumstances.

Other causes of biodiversity change

15. A wide range of pressures other than climate change affect biodiversity and may exacerbate the effects of climate change or, in rare cases counteract them. Reduction or removal of pressures that impact negatively on biodiversity can increase the resilience of habitats and associated species so they are able to cope with effects of climate change.

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16. At a global level, land-use change is predicted to have the greatest effect on the biodiversity of terrestrial ecosystems, followed by climate change, nitrogen deposition, biotic exchange (the deliberate or accidental introduction of plants and animals to an ecosystem) and elevated carbon dioxide concentrations.

17. Scientific evidence on the relative impact of climate change and other pressures on biodiversity and their interactions is often lacking. This is particularly true in the case of interactions between multiple factors.

18. Within England, the following pressures were identified as particularly important in the context of climate change:

19. Habitat destruction due to changing land use causes fragmentation and a reduction in extent of the habitat. Small areas of habitat are more susceptible to additional pressures including those associated with climate change. Remnants of habitats can offer opportunities, as sanctuaries or as sources of pioneers or colonists if changing conditions or creation of habitat favours their survival and dispersal.

20. Change in management practices can have both positive and negative impacts on biodiversity and there are opportunities for biodiversity under a changing climate by developing and promoting good practice.

21. Non-native species may cause change in community structure (through displacement or interference), loss of species and potential changes in ecosystem function, with greater sensitivity of some habitats when under increased stress due to climate change. There is potential for increased diversity where they compliment or substitute losses due to climate change.

22. Air pollution (nitrogen and sulphur deposition, carbon dioxide and ozone) can cause changes in edaphic factors, loss of species, shifts in community structure and ecosystem function.

23. Over exploitation can impose pressures on habitats and associated species, which increases their vulnerability to other pressures, including climate change.

Adapting to Climate Change

24. Policy and management responses to reduce adverse impacts of climate change on biodiversity should be a high priority for government and other stakeholders. Adaptation should focus on increasing the resilience and therefore reducing the vulnerability of natural systems, so that they can accommodate and respond to climate change.

25. Adaptation strategies must take account of uncertainty so that 'no regrets' decisions are made, which are not contingent on specific climate change or impacts scenarios. They should offer the potential for 'win-win' situations where other desirable outcomes result, as well as climate change adaptation. The concept of adaptive management provides a framework to retain flexibility and develop responses as situations develop.

26. Climate change requires a paradigm shift in attitudes to conservation. Policy targets and objectives will need to consider dynamic baselines and ecosystem properties such as resilience in future.

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27. The EBS climate change adaptation workstream members have identified four key principles for adaptation to climate change, aimed at reducing vulnerability and managing for uncertainty:

- Reduce direct impacts
- Reduce indirect impacts
- Increase resilience
- Accommodate change

28. These are generic principles and their practical implementation can be summarised as six **measures for adaptation**.

- Direct management to reduce impacts
- Promote dispersal of species
- Increase available habitat
- Promote conditions for natural ecosystem functioning
- Optimise sectoral responses to climate change for biodiversity
- Continue to reduce pressures not linked to climate change.

29. Direct management refers to situations where intervention can allow aspects of biodiversity to persist in their present locations, for example by altering microclimate or drainage.

30. Promoting dispersal of species allows species to move into new areas of suitable climate. Approaches which have been proposed include 'corridors' and 'stepping stones' between major habitat patches and improving the quality of the matrix in which those patches are found. The best means of achieving this will differ between species and habitats and requires further research and development. Effects on invasive, non-native species will need to be monitored and may in some cases require a management response. For some species with poor dispersal capacities, deliberate translocation may be an option to allow their colonisation of new areas.

31. Increasing the available habitat, either through increasing the size of existing patches or creating new patches builds resilience by increasing population sizes and can also increase heterogeneity improving the chances of establishing small areas of suitable climate for threatened species. Together with the promotion of dispersal, habitat creation can increase the likelihood of species distributions changing to reflect the change in climate.

32. Reducing other pressures on biodiversity can reduce the vulnerability of species and habitats to climate change.

33. Protected sites will remain an important part of conservation strategy, because of their existing biodiversity, low fertility soils, late successional communities and their suitability for introducing adaptation measures. They should, however, be viewed within the context of the wider countryside. Designations may need to become more flexible in situations where the biodiversity interest shifts from one location to another, perhaps designating site with potential to support species of concern.

34. There are a series of specific considerations for adaptation in each of the different EBS sectors; these are discussed with examples in the report.

35. Three key **underpinning requirements** enable these measures to be developed and implemented. They are aimed at reducing uncertainties and will provide the evidence base

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and communications to facilitate a flexible approach to implementation of adaptive measures to climate change:

- Monitoring and surveillance
- Development of the evidence base and research
- Knowledge transfer and communication

36. Long term-monitoring of species and habitats, together with the factors that control the impacts of climate change, is essential to detect changes and responses to adaptation strategies. There is scope for improved integration of existing schemes. There is also the need for monitoring which takes an ecosystem approach. Proposals to develop and extend the existing terrestrial and marine Environmental Change Networks should be implemented.

37. Development of the evidence base is important to reduce the uncertainties, improve understanding of processes that drive change and develop the capacity to forecast future change. This requires the development of theory as well as manipulative experiments and modelling techniques and must include socio-economic approaches as well natural science ones.

38. Knowledge transfer and communication are essential to the implementation of adaptation measures. Access to a robust evidence base and specialist knowledge is required to inform decisions-of policy makers and managers. Researchers need to have an understanding of the questions which policy makers and managers require answers to. It is essential to communicate consistent messages in a recognised, accessible, and straightforward way that reaches a wide audience.

1 Introduction

The England Biodiversity Strategy (EBS) “Working with the grain of Nature” (Defra 2002a) aims to ensure that biodiversity considerations become embedded in all the main sectors of economic activity that have an impact on, or relationship with, delivery of biodiversity objectives, both public and private. The strategy sets out a series of actions that will be taken by the Government and its partners to make biodiversity a fundamental consideration in five sectors;

- Agriculture,
- Water and Wetlands,
- Woodland and Forestry,
- Towns, Cities and Development,
- Coasts and Seas.

The England Biodiversity Group (EBG) published its first full report with respect to the delivery of EBS in 2006 (Defra, 2006c).

In recognition of the potential significant effects of climate change on biodiversity and possible risks to achievement of the BAP targets, a new cross-cutting workstream was established within the EBG in 2005. This Climate Change Adaptation workstream aims to provide guidance on the impacts of climate change, identify research needs and promote adaptation strategies.

This report was produced for the Climate Change Adaptation workstream to coincide with the review of the EBS in 2006 (Defra, 2006c). The aim of this work is to provide a review of the evidence of climate change impacts on biodiversity in England and to explore adaptation options. Specific objectives for each of the sectors (Agriculture, Water and wetlands, Woodland and forestry, Towns, cities and development, Coasts and seas) were as follows:

- To review and summarise the evidence for the direct impacts of climate change on biodiversity
- To identify potential changes in policies, working practices, and land use that are a response to climate change and assess the opportunities and threats to biodiversity as a result of these changes
- To assess non-climate change drivers of change and their interaction with climate change
- To identify feasible adaptation strategies in terms of policy and practice

2 Climate change

2.1 Observed climate change

The Earth's climate has experienced an average warming of 0.74 °C during the past 100 years, with much of that increase occurring in the last 50 years (IPCC, 2007). Although the Earth's climate has always varied, the current rate of climate change exceeds those experienced during any fluctuations within the last 1000 years and natural causes cannot explain all of this increase (Fig. 1) Hulme *et al.*, 2002; IPCC 2001, 2007). There is strong evidence that the majority of this temperature increase is a consequence of anthropogenic climate forcing due to increased release of greenhouse gases into the atmosphere (IPCC, 2007). The main greenhouse gas is carbon dioxide which has risen from a concentration of approximately 270 ppm prior to industrialisation to the current value of 381 ppm, largely as a result of the burning of fossil fuels (EEA, 2004). Other important anthropogenic greenhouse gases include methane from agriculture, nitrous oxide from agriculture, transport and industry and halogenated gases and ozone from industrial and domestic sources (EEA, 2004).

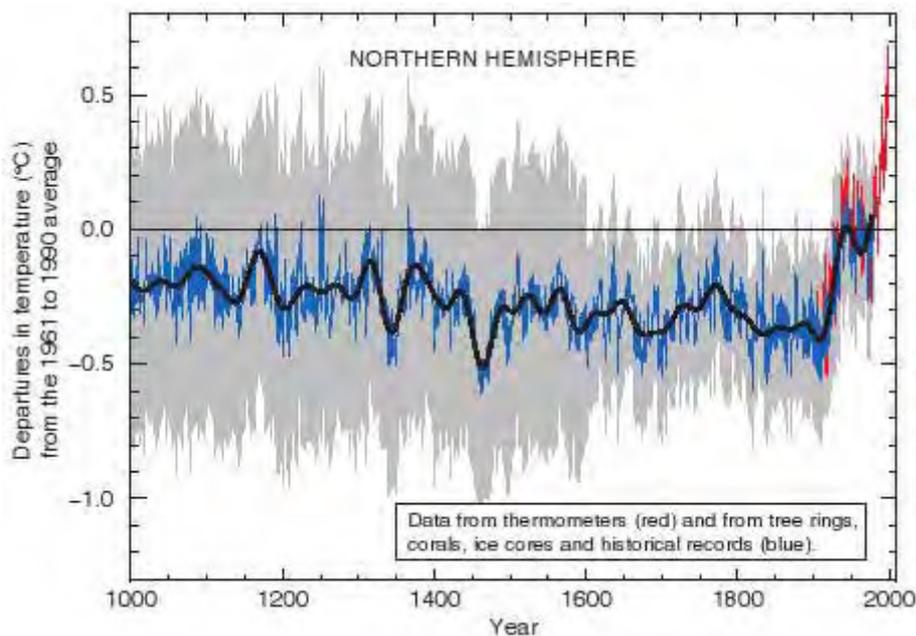


Figure 1.1 Reconstructed temperature over the last 1000 years – the classic ‘hockey stick graph’ (IPCC, 2001)

The increase in greenhouse gas concentrations causes the atmosphere to trap a larger proportion of radiant energy from the sun. As a consequence, global surface temperatures are gradually rising with the result that the temperature in central England rose more than the global average, almost 1°C through the twentieth century and the 1990s was the warmest decade since records began in the 1660s (Hulme *et al.*, 2002; Climate Change the UK programme, 2006). During the 1990s daytime temperatures exceeding 25°C in central England were almost twice as common compared to the first half of the twentieth century, while days with air frosts have been declining in frequency. The UK's thermal growing season for plants is

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now longer, by nearly a month, than since the start of the record in 1772. The warming of the Earth's climate also results in changes to other climatic variables such as rainfall, humidity and wind speed.

Winters across the UK are becoming wetter, with a larger proportion of the precipitation falling in the heaviest downpours, while summers are becoming slightly drier. Moreover, there is a gradient from northwest to southeast with winter rainfall accentuated towards the northwest and summer dryness accentuated towards the southeast (Cannell *et al.*, 1999).

The warming over the land has been accompanied by a warming of UK coastal waters. Thermal expansion of the oceans together with melting of ice caps and glaciers (Houghton *et al.*, 2001; Braithwaite and Raper, 2002; Dowdeswell, 1995) has contributed to sea level rise averaging 1mm per year during the last century around the UK coastline. The rate of sea level rise varies around the English coast, being highest on the east coast and lowest on the west coast. For example at Sheerness, on the east coast, sea level is rising by 2mm a year; in contrast records from Liverpool and Newlyn on the west coast of the England reveals no long-term (century time-scale) change (Hulme *et al.*, 2002).

In addition there have been shifts in the oceanic circulatory systems. This has resulted in changes in the distributions of fresh and saline waters in the western Atlantic with more fresh water at the poleward ends and the salinity of the upper water column increasing at low latitudes. These results provide evidence indicating shifts in the oceanic distribution of fresh and saline waters worldwide in ways that are linked to global warming and possible changes in the hydrological cycle of the Earth (Curry *et al.*, 2003). Such changes in the distribution of fresh and saline will affect marine biodiversity (Section 3.5). There is also growing concern about the observed changes in ocean acidity caused by the oceans absorbing CO₂ (Hiscock *et al.*, 2005).

2.2 Predicted climate change up to 2050

Due to inertia within the global climate system, future climate for the next 40 years has already been determined by historic emissions of greenhouse gases (Hulme *et al.*, 2002; Climate Change the UK programme, 2006). It is only beyond this time frame that the magnitude of climate change will be determined by current and future emissions. Despite our increased understanding of climate change and its drivers there is still much uncertainty with the predictions of modelled future climate change. One of the sources of uncertainty is future emissions. The UK Climate Impacts Programme (UKCIP) (Hulme *et al.*, 2002) have chosen four emission scenarios from the IPCC's special report on emissions scenarios (<http://www.grida.no/climate/ipcc/emission/>) which represent an internationally agreed range of likely future outcomes. These four emission scenarios, ranging from low to high, have been used as a basis for climate change models. These scenarios have no probabilities attached to them and no one scenario is more likely than another. This report concentrates on the predicted impacts of climate change on biodiversity up until 2050, the modelled climate change predictions from UKCIP show only small differences between the four scenarios in this time period. A summary of predicted climate change in England up until 2050 is provided below; all data are from UKCIP (Hulme *et al.*, 2002) unless otherwise specified.

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Average annual temperatures may increase between 1.5 and 2.5°C, with summer temperatures up to 3.5°C warmer in southern England and spring, autumn and winter temperatures about 2°C warmer. There may be a slight increase (0.5 °C) in diurnal temperature range during the summer, with a very small decrease in diurnal temperature range in the winter, although whether this change will have an impact on biodiversity is unknown. Extreme summer temperatures may become more frequent with hot August temperatures (such as those experienced in 1995 with an average temperature 3.5 °C above normal) occurring as often as one in five years. By contrast, very cold winters may become increasingly rare. As the climate warms, specific humidity is likely to increase through the year although the relative humidity may decrease, especially in the summer. By the 2050s typical spring temperatures are predicted to occur between one and three weeks earlier than at present and the onset of present winter temperatures is predicted to be delayed by between one and three weeks. This will lead to a further lengthening of the thermal growing season for plants. The rise in seawater temperature will lag behind air temperature increases but it is likely that average annual seawater temperatures will rise by 2 °C or more by the 2050s.

A decline of 10% in annual rainfall is predicted although this masks large seasonal changes. Summer rainfall is predicted to decrease by 30-40 % in southern England and 20-30% in northern England, while winter rainfall levels are predicted increase between 15 and 20 %. Spring and autumn rainfall may decrease by 10%. Extreme winter precipitation events and extreme summer droughts may become more frequent. Summer soil moisture may be reduced by about 30%. Cloud cover is likely to remain unchanged during the winter but may decrease by up to 8% in the summer. The English climate is predicted to become more continental.

There is greater uncertainty about the future changes in wind speed and direction. Average annual wind speed is unlikely to change much, but winter wind speeds may increase by about 5% and summer wind speeds may decrease by about 3%.

Sea levels around England could rise by 36 cm by 2050, however there will be variation around the coast due to local conditions such as tides, winds, local currents and local subsidence (Gornitz, 1995) with the most marked sea level rise in SE England (Hulme *et al.*, 2002). The average pH of the oceans is predicted to fall by 0.5 units (equivalent to a three fold increase in the concentration of hydrogen ions) by the year 2100 due to the oceans absorbing CO₂ (The Royal Society, 2005).

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Table 2.1 Summary of predicted changes in the English Climate up until 2050 based on data from UKCIP (*Hulme et al. 2002*)

Variable	Change
Rainfall	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	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	Average annual wind speed unchanged Winter wind speeds increase by 5% Summer wind speeds decrease by 3%
Sea temperature	Increase by 2°C,
Sea level	Rise of up to 36 cm
Sea pH	Acidity decrease

3 The direct impacts of climate change on biodiversity in England

Climate, soils and land management have interacted to produce the patterns of biodiversity seen in England today. Biodiversity in England is under threat from a range of anthropogenic drivers including pollution, land use change, inappropriate management and climate change. Many of these drivers interact and it is often hard to disentangle their impacts. There is “very high confidence” (as determined by the IPCC criteria) that climate change is already impacting on biodiversity (Parmesan and Yohe 2003). Evidence for the impact of climate change on biodiversity in England comes from three sources:

1. Long term site based monitoring networks have been set up to make observations of species or ecosystems.
2. Experiments that impose a change in climatic variables recorded an impact on some species in controlled situations. Such experimental results often, for logistical reasons, cannot manipulate all the climatic factors at once, e.g. rainfall and temperature, and are scale specific.
3. Prediction of the future impacts of climate change using models. Our understanding of many species and ecosystems relationships and interactions with climate is incomplete and results in uncertainty in the model outcomes.

The impacts of climate change on biodiversity will be mediated through, for example, increases in summer temperatures, increases in winter temperatures, earlier spring, summer drought, sea level rise, an increase in winter rainfall, increased CO₂ concentrations, increased stratification and changes in upwelling within oceans, and increased frequency of extreme events.

Direct impacts of climate change on biodiversity generally fall into the following categories:

- Changes in phenology (including loss of synchronicity and increased competitive advantage or some species at the expense of others)
- Changes in species distribution
- Changes in community structure (including arrival of non-natives, loss of native species and increase in pest species)
- Changes in ecosystem function
- Loss of physical space due to sea level rise and increased storminess

The direct impacts of climate change on habitats and species in each sector are discussed in the rest of this section and an overview summarising the risk of direct impacts and the strength of the evidence base is provided in section 3.6,

3.1 Agricultural and farmland habitats and biodiversity

3.1.1 Context

Agriculture has transformed the English landscape over several thousand years (Firbank, 2005). Agricultural intensification during the second half of the 20th century has created landscapes that are very productive for food but at a high cost to biodiversity, due to the impacts of drainage and reclamation, hedgerow removal, changes in cropping patterns and farming systems, and use of pesticides and fertilisers. Developments in herbicides, fungicides, fertilisers and machinery reduced the need for mixed rotations allowing farms to become more specialised (Chamberlain *et al.*, 2000; Siriwardena *et al.*, 2000). This has reduced the variety of habitats and food resources available for wildlife on many farms (Firbank, 2005; Hart *et al.*, 2006; Gregory *et al.*, 2004; Benton *et al.*, 2002; Marshall, 2003).

The emphasis in farming is now broader than maximising food production: farming is expected to produce safe, healthy products, support the viability of rural communities, operate within the biological limits of natural resources, adhere to strict welfare standards, be environmentally responsible and be flexible and close to markets (Defra, 2002b).

UK Species and Habitat Biodiversity Action Plans give explicit targets for the conservation of a wide range of species and habitats (Anon., 1995), many of which are found on farmland. In addition, the environmental costs and benefits other than biodiversity of agriculture have to be accounted for by the agricultural industry; for example the reduction of diffuse pollution from agriculture is an aim of the Water Framework Directive 2000/60/EC. Agriculture is therefore interwoven with food security and conservation of biodiversity and ecosystem services (Millennium Ecosystem Assessment, 2005).

While agricultural policy in England now has wider objectives than just food production, this needs to be set within a global context of an increasing world population. The current world population is expected to increase by 50% within the next 50 years (FAO, 2002). While increasing yields in the developed world will help sustain global food security under the current climate (Parry *et al.*, 2004) it is expected that more land will have to be brought into production to meet global food demands due to climate change at the global scale.

Land currently used for agriculture may be lost as a result of sea level rise; about 57% of Grade 1 agriculture land in the UK lies below the 5m contour leaving some of this land subject to flooding, inundation, erosion and salinisation of freshwater depending on the extent of sea level rise (NFU, 2005). If agricultural land is lost it will increase the pressure on the remaining agricultural land, which is also subject to pressures from development for affordable housing (Barker 2004) flood control and water storage schemes (see Section 3.2).

At the UK scale the ACCELERATES project (ACCELERATES, 2004) predicts that there will be no overall increase in agricultural land, just a change from extensive to intensive production with land currently abandoned being used for agriculture in some areas and some extensive farmland being abandoned in other areas.

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Predictive models (ACCELERATES, 2004) suggest that there will be a surplus of land, with some of this land available for conservation (and other) purposes. Indirect pressures on agricultural land together with CAP reform and agri-environment schemes (Sections 4.1 and 5) are likely to have a much greater impact on agricultural habitats and biodiversity than the more direct effects discussed in the next Section.

Changes in ecosystems associated with agricultural areas are likely to be affected by several climate induced changes:

Temperature. Increases in temperature will lengthen the growing season for plants. For each 1°C increase in temperature the growing season can increase by approximately 3 weeks in SE England and by about 10 days in northern areas, resulting in thermal growing conditions extending year round in SW England later this century (NFU, 2005). Increased winter temperatures will increase the risk of pests and diseases being carried over from one season to the next. 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 adaptation (Harrington and Woiwod, 1995; NFU, 2005). Warmer temperatures increase the risk of blight appearing earlier and warmer wetter winters could stimulate fungal pathogens.

Rainfall patterns and soil moisture. Soil moisture is predicted to decline by 20-50% in SE England in the summer by 2050 (Hulme *et al.*, 2002), although extreme winter rainfall and flooding may increase soil moisture at other times of year. This will affect which crops are grown and also the survival of arable weeds (NFU, 2005).

Extreme events. The predicted increase in extreme events e.g. high winds reference (Hulme *et al.*, 2002) may have a greater impact on horticulture, where the appearance of fresh fruit and vegetables is important, than on other aspects of agriculture (NFU, 2005). An increase in extreme events could potentially be more damaging than a steady long-term average change in climate.

Other interacting effects. Assuming constant inputs of soil carbon from vegetation organic matter turnover, losses of carbon in mineral and organic soils is expected to increase across the UK (NFU, 2005). This loss of soil carbon could lead to changes in soil structure and stability, topsoil water-holding capacity, nutrient availability and increased erosion. These effects could be offset by enhanced nutrient release, resulting in increased plant productivity and litter inputs. If drought is not a limiting factor, then increases in CO₂ and temperature are likely to lead to an increase in crop yields in arable systems and an increase in herbage production in pasture systems (NFU, 2005), although it is possible that herbage quality in terms of protein content will not show a commensurate increase.

3.1.2 *Direct impacts of climate change on priority habitats agricultural habitats*

Within the EBS many priority habitats are attributed to the agriculture sector because they occur within farmed systems, though these semi-natural habitats are subject to low intensity and/or specialised management (Defra, 2003). They include arable field margins, ancient species rich hedgerows, lowland meadows, upland meadows,

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heathlands, calcareous grasslands, lowland dry acid grassland and purple moor grass and rush pasture.

Models predict that **Arable field margins** are fairly resilient to climate change, with little change or an increase in suitable climate space (Berry *et al.*, 2002), i.e. the geographical area encompassing the species climatic tolerance range. While the climate space for this habitat may not change there is evidence that the vascular plant composition may change; species found in such boundary habitats have recently been shown to be increasing. Alexanders (*Smyrniium olusatrum*), common cudweed, (*Filago vulgaris*), asparagus (*Asparagus officinalis*), dwarf mallow (*Malva neglecta*), small-flowered crane's-bill (*Geranium pusillum*) and meadow brome (*Bromus commutatus*) have increased between 1987 and 2004. Climate change, particularly drier summers causing the creation of more patches of bare ground, is suggested as the driver of this change (Braithwaite, Ellis and Preston, 2006). Many rare arable species are continental species at the edge of their range (Potts, 1991) and a more continental climate may allow their population and distribution to increase. Changes in land use and agriculture practices are likely to have a greater impact than climate change on this habitat. For example farmers may spray field margins more often if they are seen as a reservoir for pests/weeds which increase as conditions get warmer. Farmers participating in the Environmental Stewardship scheme will be encouraged to adopt sympathetic management. (see Section 4.1.6).

Ancient/species-rich hedgerows are likely to be unaffected by climate change (Hossell *et al.*, 2000); although increased summer drought may cause increased death of hedgerow trees with beech trees being particularly vulnerable to this (Peterken and Mountford, 1996). Invertebrate diversity may increase as more species colonise from continental Europe, but these may include non-native invasive species whose effect on communities is unknown and may potentially bring with them an increased risk of pathogenic attack.

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. Lowland wet meadows are already under serious threat from drainage and their condition is likely to deteriorate further with increased water evapo-transpiration and abstraction during warmer, drier summers (English Nature, 2003). Low water tables are detrimental to important bird populations, which are already in serious decline in these habitats (Wilson *et al.*, 2005).

Models predicting changes in climate space within **upland hay meadows** have shown a mixed response (Berry *et al.*, 2002). Some studies have indicated that a change in species composition will occur while other studies indicate that this change depends on the farmers' response to climate change (Harrison, Berry and Dawson, 2001). 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 crane's-bill (*Geranium sylvaticum*) may decline and thus, a distinctive characteristic species of upland hay meadows may eventually be lost (Harrison, Berry, and Dawson, 2001). Globeflower (*Trollius europaeus*) is also predicted to decline while greater burnet (*Sanguisorba officinalis*) may increase leading to a replacement of upland meadows with a type similar to that found in the lowlands (Berry *et al.*, 2002; Hossell *et al.*, 2000; Harrison, Berry, and Dawson,

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2001). 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 (Braithwaite, Ellis and Preston, 2006). This provides evidence to support model predictions that the flora of northern upland hay meadows will change to one more similar to lowland hay meadows.

Lowland heathland communities are sensitive to climate change and a decrease in climate space has been predicted (Berry *et al.*, 2002). 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 (Rose *et al.*, 2000). It was speculated that this may be due to changes in climate (Rose *et al.*, 2000). 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 (Harrison, Berry, and Dawson, 2001).

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 (Britton *et al.*, 2001; Gordon *et al.*, 1999a; Gordon *et al.*, 1999b). Heather could be favoured over bracken by climate change. Heather is a superior competitor over bracken for water and warmer temperatures increase heather shoot growth but does not advance bracken emergence (Gordon *et al.*, 1999a). The competitive balance between heath and acid grassland habitats may also shift as increased decomposition rates in warmer conditions result in increased soil nitrogen levels favouring grass growth (Britton *et al.*, 2001). These climate change impacts on the ratio of bracken, heather and grass are likely to be secondary to the effects of grazing, burning and nutrient enrichment. The balance between dwarf gorse (*Ulex minor*) and western gorse (*U. gallii*) is also expected to change with dwarf gorse spreading further north and west, perhaps replacing western gorse in the west of England (Bullock *et al.* 2000). Upland plant communities are becoming more diverse, partly as a result of eutrophication but also in response to climate change (Haines-Young *et al.*, 2003; Smart *et al.*, 2003). The increase in diversity is due to an increase in generalist species, rather than typical upland species, thus altering the established community composition of many upland habitats. As the climate continues to change this advancement of generalist species into upland habitats is likely to increase.

Climate change has been shown to affect below-ground processes and soil microbial communities (Sowerby *et al.*, 2005). Changes in precipitation will affect the microbial activity within the soil, but the response depends on the moisture levels at the site. On wetter sites drought increases microbial activity, whereas on drier sites drought reduces microbial activity (Jensen *et al.*, 2003). The implications of these changes in below-ground processes on the wider ecosystem are unknown

With a prediction for drier, hotter summers, lowland heaths will be at increased risk from fire (Bond, 2005). While fire is a common management tool for this habitat and helps maintain the heather in a variety of growth forms, uncontrolled fires at the

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wrong time of year, such as those on the Dorset heaths in 1975, may damage the vegetation community (Rose *et al.*, 2000).

Upland heath and montane habitats, of which there are only small areas at their southern limits in England, 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 (Harrison, Berry, and Dawson, 2001). Most of the UK research on climate change and montane habitats is based in Scotland (Nany, 2003) but the conclusions that rare, isolated and habitat specialists, including birds such as dotterel (*Charadrius morinellus*), dunlin (*Calidris alpina*) and golden plover (*Pluvialis apricaria*) (Brown and Grice, 2005) are particularly susceptible to climate change also applies to English montane 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. Montane species such as the dwarf willow (*Salix herbacea*) and the trailing azalea (*Loiseleuria procumbens*) are predicted to have disappeared from upland areas such as the Pennines, Lake District and North York Moors where they currently occur by 2050 (Harrison, Berry and Dawson, 2001). The predictions for the stiff sedge (*Carex bigelowii*) show a similar decline in distribution, although the predictions are not as clear because, while some research shows that warmer temperatures may be damaging for the plant's root growth, the warmth could, according to studies in Iceland and Sweden, encourage its fruit to grow larger, so improving reproductive success (Harrison, Berry and Dawson, 2001). The mountain ringlet (*Erebia epiphron*), a montane butterfly, is only found in the Lake District within England and faces local extinction with climate change (Harrison, Berry and Dawson, 2001).

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 (Berry *et al.*, 2002), although its spread is limited by geology, with most calcareous substrates occurring in southern England and fragmented outcrops in the north (Duckworth *et al.*, 2000a). 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 e.g. Lizard orchid (*Himantoglossum hircinum*) (Duckworth *et al.*, 2000a). Other species, e.g. Tor grass (*Brachypodium pinnatum*), have been shown to establish successfully beyond their current distribution range if current barriers to dispersal are removed (Buckland *et al.*, 2001). 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 (Braithwaite, Ellis and Preston, 2006). 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.

The response of the calcareous grassland plant community to climate change appears to be related to the history of the grassland (Duckworth *et al.*, 2000b). Fertile

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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 (Grime *et al.*, 2000). Deep-rooted herbs and short-lived ruderal species will increase on calcareous grasslands under drought, while grasses will only increase if rainfall increases (Duckworth *et al.*, 2000a; Morecroft *et al.*, 2004; Sternberg *et al.*, 1999) which is unlikely. Therefore, as the climate changes, the plant community composition of calcareous grasslands will change with an increase in herbs and ruderal species .

Climate change, particularly the increase in mean January temperature is a significant factor in explaining the decrease in the number of species occurring on calcareous grassland between 1987 and 2004 (Braithwaite, Ellis and Preston, 2006). Species, which declined, included upright broom (*Bromopsis erecta*), dwarf thistle (*Cirsium acaule*), small scabious (*Scabiosa columbaria*), greater knapweed (*Centaurea scabies*), rough hawkbit (*Leontodon hispidus*), quaking-grass (*Briza media*), harebell (*Campanula rotundifolia*), common milkwort (*Polygala vulgaris*), wild thyme (*Thymus polytrichus*) and mountain pansy (*Viola lutea*). Species which increased included field madder (*Sherardia arvensis*) and bee orchid (*Ophrys apifera*). While such results are correlative and climate change cannot be proven to be the driver of these changes, the results suggest that climate change may be impacting on the species composition of calcareous grassland.

Changes in rainfall and temperature have been shown to affect invertebrates found on calcareous grasslands, e.g. leafhoppers (Masters *et al.*, 1998) and molluscs (Bezemer and Knight, 2001; Sternberg, 2000).

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 (Tscherko *et al.*, 2001). Additional summer rainfall will reduce N mineralisation in autumn and winter; in contrast summer drought will increase N mineralisation rates (Jamieson *et al.*, 1998). Winter warming results in decreased N mineralisation rates in spring (Jamieson *et al.*, 1998). The implications of these results on the whole ecosystem require further research.

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 (Berry *et al.*, 2002). Monarch I (Harrison, Berry and Dawson, 2001) predicted an increase in acid grassland in south-east England as wet heaths dry out and are replaced by acid grassland. Models predict that some common species such as the common storksbill (*Erodium cicutarium*) will disappear from acid grasslands as a result of drought, while the Spanish catchfly (*Silene otites*) currently common in mainland Europe but confined to the dry grasslands of Norfolk and Suffolk in the UK may spread first to Essex and then to the Midlands by 2050 (Harrison, Berry and Dawson, 2001). Spanish catchfly therefore has the potential to expand in England, but nothing is known about its dispersal ability. There has been little experimental work on the impact of climate change on this habitat. 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 (Whitehead *et al.*, 1997) (see Section on heathlands).

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Purple moor grass and rush pastures. The *Molinia*-dominated vegetation defined by this habitat includes, *inter alia*, species-rich fen-meadows for which there is considerable eco-hydrological information (Wheeler *et al.*, 2004). *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.

3.1.3 *The impact of climate change on species*

Monitoring of common farming events over 20 years has shown that climate change is having an impact on many farmland species. Events such as emergence of spring barley awns and apple buds opening were happening significantly earlier between 1990-2000 than in 1980-1990 (Sparks *et al.*, 2005). In the context of the EBS, the Agricultural sector is very broad and contains many semi-natural habitats and the species associated with them. Defra (2003) lists 4 beetles, 13 birds, 13 butterflies and moths, 12 hymenoptera, 4 fungi, 7 lower plants, 1 mammal, 19 plants and 5 other insects as BAP priority species associated with agriculture. For many of these species there is insufficient data to show whether they will be affected by climate change. Black grouse (*Tetrao tetrix*) and song thrush (*Turdus philomelos*) are thought to be detrimentally affected by climate change (Brooker, 2004). Climate envelope analysis shows substantial changes in turtle dove (*Streptopelia turtur*) distributions in response to climate warming (Gates *et al.*, 1994; Berry *et al.*, 2001). Turtle dove and other priority species such as corncrake (*Crex crex*) are long distance migrants and are at risk of a loss of synchronisation with food sources with changing phenology: the timing of their departure relies on environmental cues unconnected to climate, such as photoperiod (Both and Visser, 2001). Climate change will also have impacts on their wintering grounds and stopover points.

While the agricultural indicator species listed by Defra (2003) were not modeled by Berry *et al.* (2005), Berry *et al.* (2005) has shown that species dispersal rates are generally inadequate to match the predicted rates of change in their suitable climate space. This is likely to also be true for many of these "agricultural" species; as a result these species; may decline over time if they are not able to disperse into areas with suitable climate space.

3.1.4 *Summary: agricultural habitats*

There is evidence for climate change having a direct impact on all of the habitats within this sector.

- **Changes in phenology:** examples include impacts on migratory agricultural birds, both in their wintering grounds and in the potential loss of synchrony with food

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- **Changes in distribution:** this constitutes a major impact on most priority habitats in the agricultural sector with many examples of species altering their range in response to climate
- **Changes in community structure:** this is largely due to differences in drought tolerance leading to displacement or substitution of species within communities
- **Changes in ecosystem function:** examples include decomposition and nitrogen mineralization rates which affects nutrient availability and carbon cycling.
- **Loss of physical space due to sea level rise and increased storminess:** 57% of grade 1 agriculture land in the UK lies below the 5m contour leaving some of this land subject to flooding

For many of the semi-natural habitats included within the agricultural sector of the EBS, climate change is one of many pressures on biodiversity (see Section 5) and the direct effects of climate change may be outweighed by other changes. The indirect effects of climate change also have the potential to be as large or larger than the direct ones (Section 4.1).

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Table 3.1 Summarising the direct effects of climate change on habitats in the agricultural sector

Climate Change	Arable Field Margin	Species Rich Hedgerow	Grasslands	Heathland	Montane
Increased summer temperature	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.	Invertebrate diversity may increase as more species colonise from continental Europe, but these could displace native species	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	Wet heaths and peatlands maybe 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	Loss of montane heath.
Earlier spring	Changes in seasonal farm practices, loss of synchronicity could result in loss of species		Decrease in the number of species occurring on calcareous grassland as vernal species are out competed.		

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Climate Change	Arable Field Margin	Species Rich Hedgerow	Grasslands	Heathland	Montane
Summer drought	Changes in soil microbial activity, with effects on nutrient availability and consequences for flora.	May cause increased death of hedgerow trees, particularly beech trees.	<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.</p> <p>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.</p> <p>Summer drought will increase N mineralisation rates, but additional summer rainfall will reduce N mineralisation in autumn and winter.</p>	<p>Shift in lowland heathland communities, changes in ratio of in grassland/ heathland/ bracken.</p> <p>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.</p> <p>Changes in soil microbial activity and nutrient cycling. On wetter sites drought increases microbial activity</p>	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.
Wetter winters	As for summer drought		<p>Increase in water meadows to manage flood waters.</p> <p>In calcareous grassland grasses dominate under increased rainfall.</p> <p><i>Molinia caerulea-Cirsium dissectum</i> fen meadow is intolerant of lowering ground water in summer or flooding in winter</p>	On drier sites, drought decreases microbial activity.	

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Climate Change	Arable Field Margin	Species Rich Hedgerow	Grasslands	Heathland	Montane
Sea level rise	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				
Increased flooding			Increase in water meadows to manage flood waters		

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Table 3.2 Summarising effects of climate change on ecosystem function and species in the agricultural sector

Climate Change	Ecosystem function	Species
Increased summer temperature	Lengthen the growing season for plants. For each 1°C increase in temperature the growing season can increase by approximately 3 weeks in SE England and by about 10 days in northern areas, resulting in thermal growing conditions extending year round in SW England later this century.	<p>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.</p> <p>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.</p>
Increased winter temperature	Disruption of normal over-wintering patterns	Pests and diseases may survive the winter and increase, this may put pressure on other native species, directly or through increased use of pesticides
Earlier spring	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.	Blight may appear earlier
Increased summer drought	Soil moisture is predicted to decline by 20-50% in SE England in the summer by 2050, this will affect soil micro-organisms, crops and also the survival of arable weeds	
Wetter winters	<p>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.</p> <p>Could stimulate fungal pathogens</p>	

3.2 Water and wetland habitats and biodiversity

3.2.1 Context

This sector covers freshwaters (lakes, pools, rivers and streams) and wetlands. “Wetland” is a term used in a number of ways, and some agreement on definition is desirable. Article 2(1) of the *Ramsar Convention* (www.ramsar.org) defines wetlands as “*areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6m*”. For present purposes, the shallow marine systems are dealt with elsewhere (see Section 3.5). Wetlands can be taken to include marshes, mires, wet grasslands and floodplain forests, as well as tidal brackish wetlands.

Much of the published material referring to the impact of climate change on aquatic and wetland habitats comprises either broad predictions derived from models or studies on particular taxa with limited relevance to England and Wales. Where good experimental results exist, there are real difficulties in scaling up from the observed response of individual species to the likely response of a whole ecosystem. In addition, many investigations of wetland change in the past century confirm the importance of drainage, invasive species, pollution, urbanisation and land-use change, but as yet fail to quantify the relative contribution of climate change to the observed trends in biota (Rogers and McCarty, 2000). Hence 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) (Weltzin *et al.*, 2000). 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 (Chapin, 2003; Keddy, 2000)

Wetlands are acknowledged as having a special role within the hydrological and chemical cycles, and as the processors of waste materials from anthropogenic and natural activity. As such, they have been referred to in some publications as “the kidneys of the world” (Mitsch and Gosselink, 1986). To this role may be added a series of other functions, some linked to particular biota (harvested animals and plants), but others related to the ecosystem *e.g.* flood reduction, low flow augmentation, water quality improvement, carbon sequestration and habitat provision for many plants and animals. Wetlands are increasingly seen as essential elements in integrated water resources and catchment planning and are prominent in the Water Framework Directive (2000/60/EC; Maltby *et al.*, 2005).

The main factors affecting water and wetlands that will be altered by climate change (Cannell *et al.*, 1999; Hill *et al.*, 1999; Hossell *et al.*, 2000; Keddy, 2000; Mitsch and Gosselink, 1986) are:

- Carbon fluxes - CO₂ and methane (Pol-van Dasselaar *et al.*, 1999)
- Nitrogen mineralisation and denitrification
- Precipitation patterns – amounts, seasonality and spatial distribution

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- River flows (Arnell, 1996) – quantity, timing, duration, frequency and quality, including physical quality (e.g. temperature) and chemical quality (e.g. pH, suspended sediment load (Leeder *et al.*, 1998).
- Water supply mechanisms to wetlands e.g. impacts on groundwater recharge, flooding regimes and evaporation (Acreman and Miller, 2006).
- 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 (Shapiro, 1960).
- Primary productivity of aquatic algae in lakes (Moss *et al.*, 2003)
- Altered demand by human populations for water abstraction and land drainage (Downing *et al.*, 2003).

Such major changes (at global, regional and catchment scales) to the factors influencing aquatic and wetland habitats will either overwhelm or obscure the responses of the individual species in terms of their preferred climatic amplitudes. Nonetheless, attention should also be paid to the attributes and performance of particular species e.g.:

- Growth and productivity of dominant species under altered climate.
- Tolerances of individual species to dissolved materials, oxygenation, and sediment loading, all of which will be influenced by altered hydrology and especially runoff regimes.
- Tolerance and adaptability of individual species to changing flow regimes (which may result in shallower water or scouring/erosion of river bed, with associated changes in habitat structure).
- Soil moisture requirements of individual species. Such changes are likely to have immediate impact in marginal and ecotonal habitats, where small changes in topography and elevation may result in different soil-moisture regimes (Silvertown *et al.*, 1999).

Climate change is expected to affect temperature and rainfall patterns and associated hydrological regimes including runoff and aquifer recharge, and this will impact on aquatic environments and wetland habitat. In general, the prognosis is for hotter, drier summers and warmer, wetter winters; but the impacts of these changes are likely to vary across the England (Table 3.3).

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Table 3.3 Summary of hydrological impacts of climate change

	Change in hydrology
Average annual runoff	20% less in south east England, but 25% greater in north east England (Arnell and Reynard, 2000)
Seasonal runoff	In southern England, flow will increase in winter, but decrease in summer. (Arnell and Reynard, 2000) Rivers fed by snow melt will experience lower spring flows associated with snow-melt (Arnell and Reynard, 2000)
Low flows	Low flows in southern rivers will be lower and critical values surpassed more regularly (Arnell and Reynard, 2000)
Floods	Slight increases or decreases in flood magnitude and frequency on different rivers with no regional pattern. On average similar to current conditions (Reynard <i>et al.</i> , 2004) ¹
Groundwater recharge	Reduced in southern areas (5%), increased (5%) (Arnell and Reynard, 2000) in northern areas
Water temperature	Water temperature will rise at a rate slightly lower than that of air temperature (Webb, 1992)
Nitrate, aluminium, dissolved oxygen	Lowland rivers (less turbulent) adversely impacts; upland rivers less impacted (Jenkins <i>et al.</i> , 1993)
Acidification	Increased acidification in upland rivers (Ferrier <i>et al.</i> , 1992)

Footnote 1

(http://www.foresight.gov.uk/Previous_Projects/Flood_and_Coastal_Defence/Reports_and_Publications/Volume1/Foreword.htm) certainly predicted substantial increases in economic flood risk, but this includes effects of urbanisation and economic growth.

Changes to the hydrological regime caused by climate change will have complex impacts on ecosystems through alteration to sediment loads, flow velocity, and oxygen levels. For example, higher temperatures result in lower dissolved oxygen. Many impacts may be compounded or self cancelling; consequently impacts on specific rivers, lakes and wetlands will vary according to local conditions. Reduced groundwater recharge in southern England is likely to lead to reduced water availability in groundwater-fed wetlands such as Great Cressingham Fen in East Anglia (Whiteman *et al.*, 2004). Aquatic species tend to have tolerance ranges to environmental variables, being narrower in flowing systems like rivers and broader in still systems like ponds and lakes, some species are more sensitive to particular variables than others, but all are constrained by availability of suitable water quality and quantity.

3.2.2 Peatlands

Temperate peatlands (all areas with a naturally accumulated peat layer at the surface) hold a quarter of all soil carbon, illustrating their importance as a global sink (Moore, 2002). Peatlands can act as source or sink depending on delicate balance of climate, water supply, and temperature. The sequestered carbon may be released

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to the atmosphere following drainage or when warming climates alter soil processes toward aerobic decomposition (Keddy, 2000; Keller *et al.*, 2004). Warmer drier summers accelerate the release of CO₂ from peatlands, potentially doubling the rate (Dowrick *et al.*, 1999). The trapped organic matter also consists of proteins, representing a nitrogenous sink, and acceleration of decomposition rates also enables release of the nitrogenous material. Studies of a managed wet grassland on the Somerset Levels and Moors (Lloyd, 2006) showed that these wetlands exhibit a slight carbon loss due to peat oxidation and removal of carbon by grazing and hay-cutting; but by raising water levels and making them wetter, the carbon balance could be neutral. Soil methane emissions from wetland ecosystems can dramatically increase or decrease through alteration of hydrology (Pol-van Dasselaar *et al.*, 1999) or above ground plant diversity (Greenup *et al.*, 2000), both of which may change as a response to climate change.

The degree of summer drying is crucial, for example experimental studies show that an 8cm drawdown had no perceptible impact on nitrous oxide release, whereas more severe drought led to an exponential increase in nitrogen release or denitrification, enhancing the greenhouse effect and the deposition of nitrogen onto other ecosystems, which may in turn led to ecological responses to this nutrient enrichment (Dowrick *et al.*, 1999; Stevens *et al.*, 2004). Increasing temperatures leads to increased decomposition rates and this results in enhanced CO₂ emission and nitrogen deposition with consequent increased primary productivity (Moore, 2002). The predicted balance between increased productivity and increased decomposition is dependent upon precipitation patterns. Where summers are drier and winters wetter (as in mires within the more continental part of England e.g. the Fenland Basin, East Anglia and Lincolnshire), there is likely to be peat loss and contraction of bogs, with increased decomposition of peat making such wetlands a net carbon source (Evans *et al.*, 1999; Bardgett, 2005). Summer-dry bogs are also liable to invasion by trees, and thus accelerated water loss through transpiration, further accentuating the drying of the bog surface. Oceanic mires, such as those along the Atlantic fringe of Scotland (Bragg, 2002) and possibly on the western fringe of England, may be more secure, since the predicted increase in overall precipitation should mitigate some of the effects of warming. The implication for the conservation of such mires is that increasing amounts of winter water may have to be stored to ensure that the water needs of the fen or bog can be met through the summer months. 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 (Moore, 2002).

Climate envelope modelling predicts that the range of key blanket bog species such as hare's-tail cotton-grass (*Eriophorum vaginatum*) and bog-myrtle (*Myrica gale*) will remain unchanged (Berry *et al.*, 2002) but the distribution of cloudberry (*Rubus chamaemorus*) is likely to decline while south-western bog systems may gain species extending their range from the south (Hossell *et al.*, 2000). Tree invasion of bogs as consequence of summer drought could locally lead to increased water loss through transpiration and higher heat absorption enhancing the drying effect on the bog surface. Higher temperatures will change the soil fauna of bogs including increased enchytraeid worm density (Cole *et al.*, 2002) and enhanced increased in decomposition rates.

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3.2.3 Freshwater wetlands

Wetlands are transitional habitats between terrestrial and aquatic situations. This transitional nature is intrinsically stressed through variation in water-regime and this character renders them especially vulnerable to perturbations and change brought about by altered precipitation or temperature (Keddy, 2000; Mitsch and Gosselink, 1986). Poff *et al.* (2002) recommend that the best way to consider the impact of climate change on wetlands is through the hydroperiod i.e. the patterns of water depth and the duration, frequency and seasonality of flooding. Related approaches include the use of Sum Exceedence Values (Box 3.1) (Gowing *et al.*, 1997, 2002).

Increased levels of carbon dioxide can alter species composition in some wetlands, independently of any hydrological or temperature change, with the most responsive species out-competing the less responsive species (Arp *et al.*, 1993). Similar trends have been predicted using a dynamic model to investigate the effect of atmospheric carbon dioxide increase on plant growth in freshwater ecosystems (Schippers *et al.*, 2004). Thus under eutrophic conditions, those algae and macrophytes that use CO₂ and HCO₃⁻ proved able to double their growth rate under atmospheric CO₂ elevation, whilst those macrophytes restricted to CO₂ assimilation may show a threefold increase in growth rate. Marked changes in community composition in a wide range of wetlands would occur with the levels of elevated CO₂ that are predicted. Impacts of elevated CO₂ on invertebrates may be mediated through the vegetation. For example the leaf litter of trembling aspen (*Populus tremuloides*) produced under ambient and experimentally elevated levels of CO₂ was fed to crayfish, and their preferences assessed (Adams *et al.*, 2003). The results showed that crayfish can discriminate chemically between leaf-detritus from “ambient” and “elevated”, preferring that produced under ambient CO₂ conditions. Experiments of this type suggest changed atmospheric gas levels may have impacts on the nutrition and preferences of aquatic species.

As well as problems of scaling up from species to ecosystem responses, the impact of eutrophication on aquatic and wetland habitats, either directly or via atmospheric deposition, serves to mask the response of such habitats to elevated CO₂.

Water supply mechanisms affect the vulnerability of wetlands to drying following climate change, with rain-fed (ombrotrophic) wetlands more susceptible to change than groundwater-fed systems. Research to characterise the water supply mechanism of particular wetland communities, however, has shown that a more complex pattern than this simple categorisation (Wheeler and Shaw, 1994, 2001). The hydroperiod of wetlands is frequently influenced by the adjacent surface waters (rivers and lakes) such that any climate change that reduces the frequency and magnitude of high flows will lead to reduced inundation of the floodplain and hence changes in the wetlands present there. The environmental consequences of flood regime on floodplains have been recently reviewed by Ramsbottom *et al.* (2005). Floodplain wetlands that depend on a marked flow peak following snow-melt are especially vulnerable to climate change (Poff *et al.*, 2002). Long-term change toward higher precipitation will result in higher water-tables and hence expanding areas of groundwater-fed wetlands, whilst contraction of wetland area will follow a sustained trend toward lower rainfall. To some extent, agricultural drainage provides an

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experimental assessment of how such wetlands might respond to a drier climate (Hill, 1976).

Increased temperatures can affect wetland composition both directly and indirectly. Groundwater-fed fens tend to have a more equable regime than nearby surface waters, being cooler in summer but warmer in winter. In the northern hemisphere, this regime in fens allows species of cooler climates to survive further south than they otherwise might (Cooper, 1996). Warming of the groundwater under long-term climate change would lead to a loss of such species.

In the British situation, Hossell *et al.* (2000) summarised the possible risks to fen, marsh and swamp under predicted climate change as:

- 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.

3.2.4 Lakes and pools

A recent Dutch review (Mooij *et al.*, 2005) of the impact of climate change on lakes concluded that climate change 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.

Water-level regime in shallow lakes is regarded to be an important factor for lake ecosystem functioning and biodiversity (Coops *et al.*, 2003). Extreme water levels may cause shifts between the turbid and the clear, macrophyte-dominated state

Mooij *et al.* (2005) recommended that water managers could counteract these developments by reducing the nutrient loading, developing the littoral zone, compartmentalising the lakes and refining fisheries management.

A British study of lake phytoplankton and climate change provides valuable predictions about the impact of raised water temperature (Elliott *et al.*, 2006), and supports the second of the Dutch group's conclusions. Elliott *et al.* (2006) used a phytoplankton community model (PROTECH) to predict the effects of elevated

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temperatures and increased nutrient load on phytoplankton succession and productivity. PROTECH predicted that cyanobacteria had the potential to dominate the phytoplankton community and that this dominance was at its greatest when high water temperatures were combined with high nutrient loads, as might occur where climate change is associated with intensive farming and urbanisation.

Moss *et al.* (2003) found that climatic warming had very minor effects on chlorophyll a and total phytoplankton biovolume in shallow lakes in Northern Europe. Warming did not increase the abundance of blue-green algae (cyanophytes) in contrast to the findings of Mooij *et al.* (2005). However, it decreased the abundances of *Cryptomonas erosa* (Cryptophyceae) and *Oocystis pusilla* (Chlorophycota) and increased those of two other green algae, *Tetraedron minimum* and *Micractinium pusillum*. It had no effect on a further 17 species that were predominant in a community of about 90 species.

In lowland Scottish lakes that have been studied for several decades, annual mean water temperatures have increased by around 1°C, with proportionately greater increases in winter and spring (Carvalho and Kirika, 2003). Little correlation has been observed between annual measures of chlorophyll (i.e.. phytoplankton) and water temperature, but winter mean values of chlorophyll and water temperature show a consistent positive relationship. Most importantly, spring densities of aquatic invertebrate grazers (e.g. water flea *Daphnia* sp.) showed a stronger, significant, positive relationship with spring water temperatures (Carvalho and Kirika, 2003). Climate change impacts on such freshwater lakes may be mediated through effects on particular ecosystem components or upon nutrient availability, significantly altering the functioning of shallow lakes and seasonal patterns in water quality.

The impact of temperature on wetland animals, and especially the dynamics of breeding, has been investigated in detail through the example of the common toad (*Bufo bufo*), using a 20 year study of a breeding population in a pond in southern England (Reading, 1998; Reading and Clarke, 1999). This research not only showed how the arrival of toads at the breeding pond was correlated with the mean daily temperature over the 40 days immediately preceding, but also that early breeding was associated with warm winters. In addition the duration of the tadpole stage was negatively correlated with the date that the first spawn appeared, and indeed the tadpole stage lasted up to 30 days longer in early spawning years than in late ones.

One of the UK Government Indicators of Climate Change (George, 1999) is the number of days on which ice is recorded on Lake Windermere. The number of ice-days declined during the late 1980s and 1990s associated with mild winters and high values of the North Atlantic Oscillation (NAO) index. Predicted emergence dates for adult mayflies have been shown to vary by nearly two months between years, depending on the phase of the NAO (Briers *et al.*, 2004). Such variation in the growth and phenology of aquatic insects could also affect temporal fluctuations in the composition and dynamics of stream communities.

Jöhnk *et al.*, (2005) studied the impact of climate change on lake stratification in Europe. Results for a “warm future” scenario compared to the situation today show, that not only lake surface temperature will increase, but also the period of stagnation will extend by up to 4 weeks and the duration of ice cover decrease by 1 – 2 months,

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but the absolute values will depend on the geographical location (latitude, elevation). These climate induced changes in stratification and mixing have major impacts on plankton abundance, e.g. earlier timing of the clear-water phase (up to 4 weeks), and composition, e.g. competitive advantage of buoyant phytoplankton in case of more stable stratifications. Therefore the occurrence of massive blooms of buoyant cyanobacteria is more probable in a warmer future climate, in keeping with the findings of Mooij *et al.* (2005).

3.2.5 Rivers

Warmer, drier summers and wetter winters will lead to a range of direct and indirect impacts on river ecosystems. Webb and Walsh (2004) examined the impact of changes in river temperature on freshwater fish. They concluded that three rivers (of the 27 studied) that currently are inhabited by Atlantic salmon will have adverse conditions for spawning and embryo survival in the future. It is predicted to affect the Rivers Barle and Test by 2050 and the River Medway by 2020. By 2080, 12 of the study-rivers are predicted to be uninhabitable to salmon and some other fish with sites in the south and east of England most affected.

3.2.6 River floods and floodplains

Flooding is a natural part of the hydrological regime of most river systems. Floods are important in landscape evolution and in maintaining the physical structure of the channel by flushing and sorting sediment, they trigger migration and facilitate the exchange of nutrients and species between the river and its floodplain (Poff *et al.*, 1997; Junk *et al.*, 1989; Hill and Beschta, 1991). Floods may destroy parts of the river ecosystem, but create new habitats that provide the opportunities for species. Over short time periods, floods may be seen to be detrimental. For example, the heavy rains and subsequent widespread and prolonged flooding in autumn 2001, particularly in floodplains, appears to have been responsible for an increased incidence of non-breeding and poorer breeding success by barn owls (*Tyto alba*), probably because their small mammal prey populations had been reduced by the flooding (Leech *et al.*, 2004). Increased frequency of floods will result in changes to erosion sediment transport and deposition and in turn to habitat structure. For example, many fish species, particularly salmonids, have threshold tolerances to suspended sediment concentrations and durations (Newcombe and Jensen, 1996); thus any increases could have significant impacts. Salmonid spawning gravels can also be degraded by clogging with fine sediment when flows are reduced.

Although most climate models predict drier summers and wetter winters in the UK, detailed predictions of impacts on river flow regimes vary. Reynard *et al.* (2004) concluded that floods would be more severe on some rivers and less severe on others, with no distinct regional pattern, based on outputs from the Hadley Centre global climate model. Overall flood magnitude and frequency is likely to be similar to current conditions in the future. This suggests that the associated behaviour pattern of river ecosystem biota, such as movement of fish species on to floodplains (such as dace) or to breed in backwaters (such as pike) may show local impacts, but may be largely unaffected at a national scale. Likewise, habitat and invertebrate food for other floodplain users such as birds (e.g. redshank (*Tringa totanus*) and lapwing

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(*Vanellus vanellus*) will not be affected at a broad scale. Other models suggest there may be more frequent inundation of floodplains.

Feeding conditions are usually better for many species at the margins of flooded areas, so several smaller areas of floodwater are usually more beneficial to waterfowl than one large one. Flooding of terrestrial habitats and standing water causes the death of many soil-dwelling invertebrates. This can result in short-term benefit to the birds, but prolonged flooding can greatly reduce the food supply available to feeding waders (Ausden, Sutherland and James. 2001).

The Foresight programme (http://www.foresight.gov.uk/Previous_Projects/Flood_and_Coastal_Defence/Reports_and_Publications/Volume1/Foreword.htm) predicts substantial increases in economic flood risk which includes increased urbanisation and economic growth. Flood risk management is likely to be increasingly concentrated in urban areas where the demand is highest and benefits greatest; many rural defences may not be maintained, leading to more inundation of floodplains, even if floods are less severe or similar to present. The outcomes for biodiversity could be positive or negative depending on decisions that are made on how best to adapt to meet social and environmental objectives.

The primary constraint placed on vegetation by flooding is via soil waterlogging and hence the development of anoxic conditions in the plant root-zone (Ramsbottom *et al.* 2005). Depending on its duration, flooding can have the following physicochemical effects:

- Restrict gas-exchange in the soil, depleting oxygen and leading to the accumulation of CO₂, methane and nitrogen.
- Thermal effects e.g. altered radiation absorption and reflectance, modified heat flux *etc.*
- Alterations to soil structure e.g. increased soil plasticity, breakdown of crumb structure and swelling of soil colloids.

Where flooding is prolonged, aerobic soil organisms (such as fungi) are replaced by obligate anaerobes (e.g. bacteria), with the following consequent effects on the soil as a growing medium for plants:

- decomposition rate of organic matter is reduced,
- nutrient and electrolyte concentrations in the soil solution are diluted,
- the redox potential of the soil is reduced, and pH tends to rise.

3.2.7 *Low flows and river ecosystem response*

Higher temperatures (and associated higher evaporation) and reduced summer rainfall, will reduce future river flows in the summer compared to current levels, although model uncertainty means we cannot be sure about the magnitude of impacts. Wilby and Harris (in press) estimated that for the River Thames, which is taken as a representative river for south-east England, there is an 80% chance there will be some reduction in low flows by 2020 and a 10% chance that the reduction will be 10%. This will have a number of impacts on river ecosystems; reduced flows can

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increase temperature, reduce dissolved oxygen and increase light penetration. Many river species have narrow or specific habitat requirements including critical levels of water depth and flow velocity. Reduced flows in the summer will lead to loss of available habitat during critical periods. This could impact on juvenile salmonid fish (Dunbar *et al.* 2001) and other species dependent on higher flow rates or river margin habitat. In the past one of the UK Government Indicators of Climate Change (Cannell *et al.* 1999) was the upstream migration of salmon, which is dependent on flow rates and so is expected to decline with drier summers.

3.2.8 *Impact of climate change on species*

Global and regional (and catchment) changes will be mediated through the differential responses of the various species that occupy an aquatic or wetland habitat, resulting in altered competitive balance and development of communities with a different composition (at least in terms of the proportions of species). Observed differential responses of species, life-forms, and above- and below-ground biomass production to experimental treatments mimicking climate change (warming and altered water-table) imply that mire plant communities will change in different directions and to different degrees (Weltzin *et al.* 2000). Assuming climate niches of plants remain unaltered in the medium term, climate change will result in different distributions of individual species and different overlap in the distributions of key components of wetland communities, potentially resulting in disrupted community structure and new combinations (Hill 1995). Thus, predicting the response of wetlands and aquatic habitats to changed climate 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. These “.....differential responses could result in a disruption of the connectedness among many species in current ecosystems (for example, a tearing apart of communities)” (Root *et al.* 2003).

The various life-forms associated with aquatic and wetland systems have considerable diversity in their specific tolerance ranges to a wide array of environmental factors. They also show variety in their capability to respond to changes in these factors. For example, different plant species that coexist within the same vegetation community display different ecological ranges with respect to hydrology (Hill *et al.* 2004; Silvertown *et al.* 1999). Should this wetland be perturbed in some way, the composition will alter, with some species becoming extinct, some colonising and others showing changes in abundance. It is thus not surprising that climate change at global, regional and catchment scales may result in differential responses of the various species that occupy an aquatic or wetland habitat, resulting in altered competitive balance and development of communities with a different composition (at least in terms of the proportions of species). Three categories of impact can be expected resulting from climate change:

- With warmer waters and lower oxygen concentrations, there will be a) impacts upon organisms with narrow tolerance ranges; b) effects on bacterial activity and changes to nutrient cycling regimes; and c) changes in the growth rates of organisms, including plants and immature animals.

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- Following changes in water quality especially with greater sediment loading, the likely effects are a) sediment blanketing influencing primary production in flowing systems (e.g. rivers); b) sediment accumulation accelerating accretion of and hydrosereal succession of marshes and reed beds to carr and woodland; and c) increased concentration of soluble materials leading to toxicity or eutrophication.
- Changes in availability of water and effects of hydrology and differential flows will lead to either scouring effects or loss of marginal habitat during low flows, and in some instances to lowering of water tables and reduced aquifer recharge. Each change, whether leading to higher or reduced flows, will have resulting impacts on habitat structure.

3.2.9 Summary: water and wetlands

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 peatlands and wetlands.

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Table 3.4 Summarising direct effects of climate change on habitats of the water and wetlands sector

Climate Change	Freshwater wetlands (in the broad sense)	Peatlands (bogs and fens)	Floodplain wetlands	Lakes, pools and other still waters	Rivers
Increased summer temperature	<p>Groundwater-fed wetlands more resilient to temperature change than ombrotrophic sites. Accelerated transition to terrestrial habitats, partly through increased evapotranspiration. Change in species composition toward more continental and/or southern species.</p> <p>In combination with higher CO₂ levels, increased productivity and changes in grazing preference of some invertebrates</p>	<p>Loss of peat through aerobic decomposition – increased loss of CO₂ and release of NO_x. Soligenous mires may dry out in summer (via rise in evapotranspiration <i>etc</i>) with trees colonising.</p> <p>Reduction in circumpolar boreal-montane species.</p> <p>Variable responses in mire plant communities, with disruption in composition and structure</p> <p>Increase in density of Enchytraeid worms</p> <p>Increased incidence of fires</p>	<p>Incidence of flooding similar to current or reduced.</p> <p>Geographical changes in waterfowl breeding</p> <p>Raised productivity of wetlands</p>	<p>Water tends to buffer effect of raised temperature.</p> <p>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.</p> <p>Benefit invasion of species with currently eastern distribution</p> <p>Disrupted stratification of lakes <i>etc</i></p>	<p>Water tends to buffer effect of raised temperature.</p> <p>Decreased river flow with critical values for biota exceeded and loss of habitat</p> <p>Reduced suitability for Salmonid breeding</p>
Increased winter temperature	<p>Some continued evapotranspiration</p> <p>Survival of more pathogens</p>	<p>Reduction in extent of boreal bryophytes <i>etc</i></p>	<p>Geographical change in waterfowl wintering</p>	<p>Reduced duration and extent of ice cover.</p> <p>Higher levels of phytoplankton and earlier breeding of some species</p>	<p>Increased river flow, tempered by increased evaporation</p>

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Climate Change	Freshwater wetlands (in the broad sense)	Peatlands (bogs and fens)	Floodplain wetlands	Lakes, pools and other still waters	Rivers
Earlier spring	Phenology: altered breeding/flowering times. Loss of synchronicity resulting in disrupted ecosystem function		Decrease in the number of strictly vernal species in floodplain grassland due to competition from productive grasses	Increased densities of aquatic invertebrate grazers Altered breeding of <i>Amphibia</i> , and emergence of mayflies <i>etc</i>	Change in the seasonal timing of peak flows
Summer drought	Closely linked to increased summer temperature. Changes in soil microbial activity, with effects on nutrient availability and consequences for flora	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 <u>increased</u> precipitation)	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.	Encroachment of marginal emergent vegetation zone Shallow water-bodies may become only seasonally wet and transient	Chronic low flows with risk of deoxygenation and disrupted connectivity along river Loss of instream physical habitat
Wetter winters	More prolonged waterlogging resulting in altered community composition Need to increase flood-storage through constructed wetlands		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 (see Agricultural sector)	Flooding higher up shoreline, displacing the drawdown zone	Generally higher winter flows – but possibly with somewhat smaller flow peaks following melt of smaller quantities of snow

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Climate Change	Freshwater wetlands (in the broad sense)	Peatlands (bogs and fens)	Floodplain wetlands	Lakes, pools and other still waters	Rivers
Sea level rise	Coastal freshwater and brackish wetlands subject to flooding and salinisation.	Few peatlands survive in the coastal zone, but those that do (Broads, Somerset Moors etc) vulnerable	Change from freshwater swards (MG5, MG8, MG9, MG10 etc) to those tolerant of brackish conditions (MG11, MG12 etc)	As freshwater wetlands and peatlands – some Broads vulnerable. Increased incidence of brackish lagoons	Alteration in estuarine ecotone and sedimentation patterns
Increased flooding	Increase in constructed wetlands (water meadows, Great Fen <i>etc</i>) in order to manage flood waters	Reversion from fens to swamps, and tendency for bogs to lose obligate calcifuge species as ombrotrophic regime disrupted	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	Similar impact to wetter winters	Increased erosion and sediment load with impacts on fish suitability
Increased frequency of extreme events	Impacts on species recruitment and community regeneration	Loss of mires through fire or flooding	Communities dependent on regular moderate flooding disrupted	Loss of species with narrow ecological amplitude	Rapid changes in channel morphology following flash floods

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Climate Change	Freshwater wetlands (in the broad sense)	Peatlands (bogs and fens)	Floodplain wetlands	Lakes, pools and other still waters	Rivers
Associated factors		Increased pollution risk from runoff from surrounding farmland			Increased acidification in upland rivers

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Table 3.5 Summarising effects of climate change on ecosystem function and species in the water and wetlands sector

Climate Change	Ecosystem function	Species
Increased summer Temperature	<p>All changes will have most marked impact in ecotonal habitats, altering their distribution, width and composition</p> <p>Changes in the growing season for plants (see agricultural sector, Section 3.1) and hence on productivity and energy fluxes.</p> <p>Effects on bacterial activity and nutrient cycling, including carbon fluxes (notably within peatlands) and patterns of nitrogen mineralisation and denitrification</p> <p>Altered evapotranspiration</p> <p>Reduced water availability and quality</p>	<p>Impacts on organisms with narrow tolerance ranges</p> <p>Changes in growth rates of organisms</p> <p>Conditions more favourable for species of currently southern, eastern and Continental distributions</p>
Increased winter temperature	<p>Disruption of stratification (thermocline and nutrients)</p> <p>Altered evapotranspiration</p>	<p>Decline in species of boreal and circumpolar distribution</p> <p>Changes in migration patterns of wintering birds</p> <p>Altered survival of wetland invertebrates</p>
Earlier spring	Differential responses may result in a disruption of the connectedness among species in current ecosystems	Individual species displaying different responses – hence ecosystem response
Increased summer drought	<p>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</p> <p>Reduced summer groundwater recharge (but variation between south and north)</p> <p>20% less annual runoff in south and east (25% higher in northeast) with altered seasonal distribution</p>	<p>Reduced vigour and/or death of hydrophytes and helophytes</p> <p>Reduced feeding opportunities for wetland animals, resulting in reduced breeding success</p>

3 The direct impacts of climate change on biodiversity in England

Climate Change	Ecosystem function	Species
Wetter winters	<p>(As in agricultural sector Section 3.1) - winter rainfall and flooding may increase soil moisture, changing microbial activity, nutrient cycling and associated species supported.</p> <p>Increased groundwater recharge</p>	<p>Changes in feeding opportunities for wintering animals</p> <p>Duration of wet conditions affecting competitive interactions during spring and hence community composition</p>

3.3 Woodland and forestry habitats and biodiversity

3.3.1 Context

After the end of the last ice age, approximately 10,000 years ago, England was re-colonised by tree species until broad-leaved, deciduous forest spread to all but the highest and wettest areas (although not all areas may have had dense forest cover) (Peterken, 1996). This has been progressively cleared by people since around 5000 years ago. Currently, woodland in England covers 7% of the surface area and is highly fragmented; over 80% of ancient woodland sites are less than 20 ha in extent (Thomas *et al.*, 1997). All of these fragments have been subject to some human intervention, but ancient semi-natural woodlands (known to be woodland in 1600 and which have not been subject to clear felling and replanting) are generally believed to have some continuity of species composition with the pre-historic 'wildwood'.

Because trees take a long time to grow to maturity, woodland management is planned on timescales of decades. Decisions taken now will have direct implications for the rest of this century and well into the next. It is therefore very important to take account of climate change in developing forestry and woodland nature conservation policy. This has been recognised and has been the subject of a number of studies and conferences (Broadmeadow, 2002; RHS, 2005a).

The impacts of climate change need to be considered alongside other pressures on woodland biodiversity, such as the impacts of invasive species, atmospheric pollution and the rising deer population which impose grazing pressures. The role of management has historic importance in shaping English woodland and species diversity as we see it today. In recent decades there has been an emphasis on restoring traditional management practises, particularly coppicing, to enhance both structural and species diversity and there is considerable interest in restoring traditional landscapes, such as parkland. The main emphases of UKBAP targets for woodland priority habitats are: (1) increasing the proportion of sites in favourable condition, (2) expansion of total areas and (3) restoration of a proportion of ancient woodland sites to site-native species composition where they have been replaced by non-native plantations (UKBG Tranche 2 Action Plans (volume II)).

Climate has a clear influence on English woodlands which can be seen in the geographical variations in plant community composition (Rodwell, 1992) and the tolerances and suitability of tree species for planting in different areas (Pyatt *et al.*, 2001). A number of impacts of recent climatic conditions can be also identified. 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 (Sparks and Carey, 1995; Sparks, 2000). (Similar patterns have been seen for those animal groups for which phenology has been monitored, e.g. Roy and Sparks, 2000.) The impact of extreme climatic events, particularly the drought of 1976 (Peterken and Mountford 1996; Coultherd, 1978) and gales in 1987 (Kirby and Buckley, 1994) have been documented. It is not possible to attribute any single extreme event to climate change, but they do provide an insight into how the impacts of climate change may be manifest. An increased frequency of summer droughts is predicted, particularly

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for SE England under most climate change scenarios and an increased frequency of high windspeeds is also possible (Hulme *et al.*, 2002). Drought is likely to be an important issue for the future impacts of climate change on woodlands in England.

3.3.2 *Impacts of climate change on habitats*

The main impacts on UK BAP habitats are summarised in Sections 3.3.3 and 3.3.4, with impacts on species and communities given in Section 3.3.5, although there is some overlap in the treatment of tree species between communities and species. Impacts are likely to result in response to increased temperature, increased drought and associated increased fire risk, and increased incidence of extreme events with risk of windthrow. Woodland may become increasingly important to people through ecosystem function and provision of services, such as interception of rainfall and control of erosion or provision of shelterbelts and cool shaded areas.

3.3.3 *Broad Habitats*

Broadleaved, mixed and yew woodland. This broad habitat contains all of the priority habitats relevant to England. The natural range of this broad habitat type would cover almost the whole country, but its distribution is determined mainly by historical management factors. As it is well within its climatic tolerances in England, rising temperatures are unlikely to present a direct threat to the persistence of the broad habitat, although it may well change its species composition (see Sections 3.3.4 and 3.3.5). An increasing severity of drought is likely to have a greater impact and could potentially result in loss of the broad habitat itself, where canopy cover is exclusively made up of drought sensitive tree species (especially beech, *Fagus sylvatica*; Broadmeadow, 2002, 2005). Drought, like temperature, is more likely to cause an adjustment of species composition and dominance (Section 3.3.4), rather than loss of woodland.

An increase in the incidence of fires is likely to accompany an increased incidence of drought, as was seen during the 1976 drought (Coultherd, 1978) and could result in the loss of woodland. Fire risk would depend on management strategies adopted in response to this increased threat.

Sea level rise is not a serious threat to most British woodlands, although it may be locally important. The National Inventory of Woodland and Trees (which includes woodland areas over 2 ha) shows a total 9739 ha of woodland - just under 1% of the total - falling within the Environment Agencies tidal flood risk maps (M. Broadmeadow, K. Kirby, pers comm.). Of this area the majority is deciduous or mixed woodland, but only 154 ha is ancient semi-natural woodland.

In an earlier review of impacts of climate change on biodiversity at the UK scale, Hossell (2000) rated vulnerability of this broad habitat to climate change as 'low-medium', with all of the priority habitats apart from lowland wood pasture and parkland (rated 'low'), rated as 'medium'. This reflected an assessment that change would take a long time to occur, although the importance of extreme events, such as droughts and severe storms was highlighted. Since that report was written global circulation and regional climate models have developed further and UK predictions are now suggesting a greater decline in summer rainfall over much of the UK (Hulme

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et al., 2002). The chances of severe summer drought are particularly high for the south-east of England and within the English context, Hossell's (2000) assessment probably now underestimates the vulnerability of the habitat to some change.

Coniferous woodland. In England, this essentially consists of non-native plantations. The suitability of different species for different sites is likely to change (Broadmeadow *et al.*, 2002, 2005), but the persistence of the habitat itself will depend on direct management decisions rather than climatic conditions.

3.3.3 Priority Habitats

Lowland beech and yew woodland. A number of modelling and monitoring studies have shown the sensitivity of beech to drought (Peterken and Mountford, 1996; Broadmeadow *et al.*, 2002, 2005; Harrison *et al.*, 2001) and this could have a major impact on the persistence and health of this woodland habitat under climate change. At present its distribution is biased towards the southeast, where the threat of drought is most serious under climate change scenarios. Planting of beech trees in the north and west has typically been discouraged by conservationists as the species is not naturally found there and in some cases management plans have aimed to remove it from sites (Wesche, 2003). The current distribution of beech probably reflects the time required for the species to spread since re-colonisation after glaciation and the start of forest clearance (beech was the last native tree species to reach Britain (Rackham, 1986). There is no reason to suppose that beech would not have reached the north and west naturally. There is growing support for actively supporting the planting of beech in the north and west where suitable climate space is likely to persist (Wesche, 2003).

Whilst beech is likely to decline in the South and East (Figure 3.1) and cease to be a suitable timber tree (Broadmeadow *et al.*, 2005) it will not necessarily disappear (e.g. Hossell *et al.*, 2005, for Hampshire) altogether. Local differences with soils and topography would be expected. In particular, beech trees growing on chalk soils are able to access water from greater depths because of the nature of the chalk matrix (Roberts and Rosier, 2006), limiting the impact of summer droughts; it is also possible that beech would persist in wetter or more shaded sites (e.g. north-facing slopes). Further research is required to examine the extent to which these factors are important. Simulations of the effects of climate change on yew, (*Taxus bacata*) (Harrison *et al.*, 2001) suggest that it is likely to be able to continue to grow in the places throughout its current UK range.

Lowland wood-pasture and parkland. This habitat is essentially determined by management history. Climate change, particularly drought, is potentially a threat to old veteran trees, but the persistence of the habitat will depend on management decisions, such as replanting and choice of species.

Upland mixed ashwoods. There is no evidence to suggest that the habitat is likely to be at threat from climate change, although there is insufficient information and research at present. As well as ash (*Fraxinus excelsior*) the dominant tree species in this habitat include oak (*Quercus robur / petraea*), hazel (*Coryllus avellana*) and birch (*Betula pedula / pubescens*). These species are likely to be able to persist in the changed climate of the north and west, where this habitat currently occurs. The

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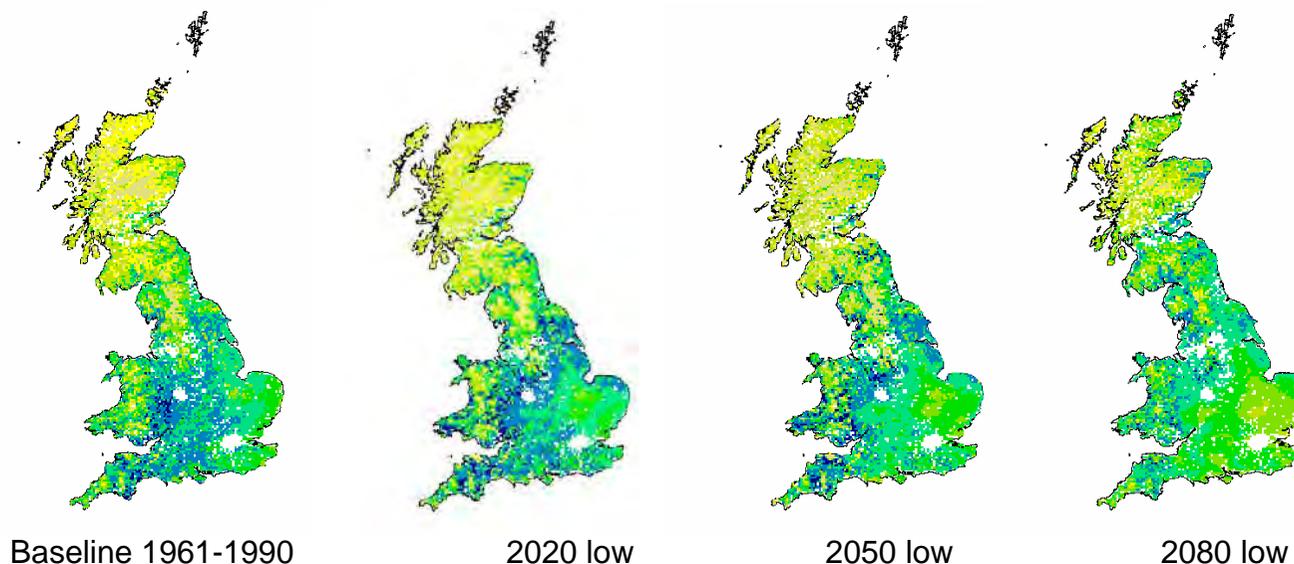
species composition may however change; one notable possibility is that the small leaved lime (*Tilia cordata*) may expand its distribution in these types of woodland. Small leaved lime is currently relatively rare, despite being one of the most abundant species in the 'wildwood' and is limited by its inability to set seed at low temperatures (Pigott and Huntley, 1978, 1980; Huntley and Pigott, 1981).

Upland oakwood. These woodlands are restricted to oceanic western areas with high precipitation and have a very restricted distribution in England. Much of the importance of these woodlands for biodiversity is due to the occurrence of species with oceanic distribution, particularly ferns, bryophytes and lichens. These taxa may be especially sensitive to changes in humidity and temperature.

Wet woodland. Wet woodland is found on poorly drained or seasonally wet soils. There is little evidence available to assess its future persistence and it is likely to depend on local and regional factors. Although the south east region is predicted to experience more summer droughts which potentially threaten the habitat, it is also likely to experience wetter winters. This may offset the effects of drought if winter rainfall is retained within catchments, causing high water tables to be maintained longer into the summer than would otherwise be the case.

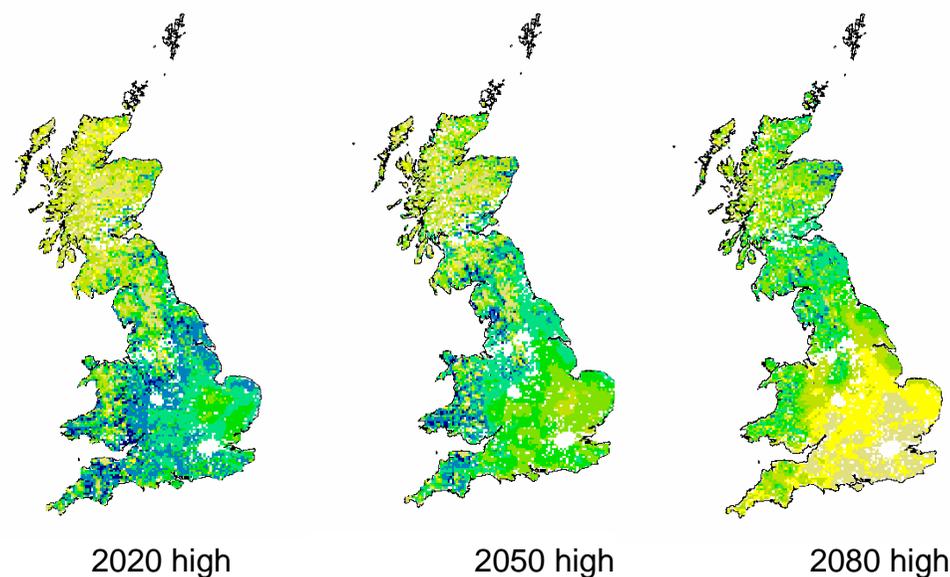
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Figure 3.1 The suitability of different areas of the UK for beech under low and high emissions scenarios for 2020, 2050 and 2080



Caveats that need to be applied to interpretation of ESC-based regional predictions of future species suitability

- 1) The predictions are indicative.
- 2) Particularly for the more extreme scenarios (both time and GHG emissions levels), the ESC models are operating well outside their 'knowledge-base', and can be no more than preliminary; in some cases, the models need extending to account properly for the climate of the future.
- 3) The beneficial effects of rising atmospheric CO₂ levels are not accounted for.
- 4) A changing incidence of pest or disease outbreaks are not accounted for.
- 5) The predictions are for 'mean climate' with an implicit assumption of the current frequency of extreme events. If extreme climatic events do become more frequent (particularly drought), the model may underestimate the effect on yield.
- 6) The output represents soil type expressed as the dominant soil type in an individual 5 km grid-square (ie, very coarse spatial representation). Where a grid-square is deemed 'unsuitable' there will be soils where a given species might be highly productive. The opposite will also be true. More detailed analysis was conducted for a few species under one scenario, and there was minimal difference between 250 m and 5 km resolution when averaged over Conservancies.



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3.3.4 *Impacts of climate change on species*

Woodland species of plants and animals are frequently specialists that are poorly adapted to survive in open areas. They range from vernal flora, such as the bluebell (*Endymion non-scripta*), to deadwood specialist invertebrates, woodland mammals such as the dormouse (*Muscardinus avellanarius*) and woodland birds, such as the pied flycatcher (*Ficedula hypoleuca*) and blue tit (*Parus caeruleus*). For the plants and most of the invertebrates, the deciduous woodland microclimate is critical. The forest floor is dark in summer but relatively light in winter and spring, moist for much of the year and its temperature is buffered against extremes. For birds and mammals the structure of the forest is more directly important by, for example, providing suitable nesting sites. The presence of trees is the key factor, together with seasonal continuity of different foraging resources such as spring flower nectar, summer insects and autumn and winter nuts and berries. Climate change will not cause woodlands to become completely different habitats: even where sensitive tree species such as birch, beech or sycamore (*Acer pseudoplatanus*) die, other tree species would be expected to replace them. The evidence suggests that much of the distinctive biodiversity of woodlands can be conserved with appropriate management. This does not imply that there is room for complacency.

Higher tree growth rates are likely in the north and west as a result of warmer temperatures and rising carbon dioxide concentrations, but in the south and east, these effects will be over-ridden by those of drought (Broadmeadow *et al.*, 2005). Higher productivity is not simply associated with higher timber production, it also implies more leaf production and hence a denser canopy in the north and west. In contrast more open areas in woods would be expected in a drought prone south-east. There will also be adverse effects on some species either through direct climatic effects or a disruption in the equilibrium of competitive or trophic relationships. In some cases the presence of particular tree species is important because other species are dependent on them, such as epiphytes and canopy invertebrates.

The effects of temperature. Most species in English woodlands are not at the southern limits of their range (unlike, for example, montane species). They are therefore unlikely to die either as a direct result of exposure to high temperatures or competitive exclusion by species they currently co-exist with (Morecroft and Paterson, 2006, consider some of the general principles underlying changes in plant communities under climate change). There are some exceptions, however, and modelling work (Berry *et al.*, 2005) has shown that the hawfinch (*Coccothraustes coccothraustes*) may lose climate space in the south of England. In contrast, woodland species at their northern limits may well expand their range and increase in numbers. There is evidence of this taking place in the speckled wood butterfly (Hill, Thomas and Huntley 1999). This is less likely to occur in less mobile groups than the butterflies, especially given the fragmented nature of English woodlands (Thomas *et al.*, 1997). Modelling, taking into account dispersal (Berry *et al.*, 2005) has however shown that it is possible in the yellow necked mouse (*Apodemus flavicollis*) in a case study on Hampshire. More mobile species from continental Europe may also begin to colonise. Increases in some species may result in competitive exclusion of other species whose growth or population response to rising temperatures is less positive, even if they are able to survive. Changing phenology may also lead to changes in

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the ground flora. Earlier development of the canopy means that the period in which the forest floor experiences high solar radiation levels is shifted to earlier in the year, when day-length is shorter, reducing potential for growth. Change could also result from the loss of synchrony between different elements of food webs or between flowers and their pollinators and there is some evidence for this from studies of year to year variations in phenology and populations (Fitter and Fitter, 2002; Perrins, 1991; Buse *et al.*, 1999). Some high priority species (e.g. spotted flycatcher (*Muscicapa striata*) are long-distance migrants and adjustment to temperature change may be constrained by departure from their wintering grounds, the timing of which relies on factors unconnected to climate change such as photoperiod (Both and Visser, 2001). Increases in temperature are also predicted to allow many woodland pests e.g. oak jewel beetle (*Agrilus pannonicus*) and pine weevil (*Hylobius abietis*) to increase (Broadmeadow, 2005). Mammal populations, including those which can cause damage to woodlands such as deer species and grey squirrel (*Sciurus carolinensis*) are also likely to show increases as a result of lower winter mortality.

The effects of changing rainfall patterns. The shift towards more precipitation in winter and less in summer in the southeast is potentially the most important aspect of climate change for woodland biodiversity. The drought sensitivity of major tree species, particularly beech, birch and sycamore (Broadmeadow, 2005) is important both directly and in forming the basis of habitats, as discussed above. Beech presents the most serious issues and has already been considered. Birch species (*Betula pubescens* and *B. pendula*) are native species that are widely distributed throughout the UK and readily colonises open ground (Grime, Hodgson and Hunt, 1988). Birch species are expected to continue to thrive in the north and west and are likely to persist in the south and east, even if rarely forming long-lived stands in this area. Sycamore is a non-native species and controversial amongst conservationists; some view it as a problem, but its impact on biodiversity targets is not necessarily adverse and it is likely that given time it would have colonised the UK without human intervention (Peterken, 2001). Increased drought is likely to cause a decrease in the abundance and vigour of sycamore in the south and east; it is, likely to continue to persist in the north and west which is where its adverse impacts, for example the colonisation of upland mixed ashwoods, are greatest.

Many ground flora species appear to be relatively resistant to drought events (unpublished data from Environmental Change Network), perhaps because of their early season growth. Repeated dry summers may reduce the abundance of fern species, exaggerating the east-west pattern which is currently demonstrated with greater abundances in the wetter west (Rodwell, 1992). Where tree species do die, there is likely to be an increase in light-demanding ruderal plants and a decline in shade tolerant woodland species. This would be short-term, assuming regeneration occurs; this in turn will depend on the presence of drought-tolerant species within the community and a relatively low level of herbivory, particularly by deer. Both of these aspects can be controlled by management. There are also likely to be winners and losers amongst the invertebrates, with northern species and those of wet places tending to decline (Morecroft *et al.*, 2002). Bird species of damp woodlands, such as willow tit (*Parus montanus*) are also likely to be detrimentally affected (Berry *et al.*, 2002). An increase in the amount of dead wood would be expected to have

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beneficial effects for biodiversity, increasing the habitat resource for specialist invertebrate (such as the staghorn beetle) and fungus species.

High windspeeds. An increased incidence of gales is a possible, but uncertain element, of climate change. Increased gales could increase incidence of windthrow, damage branches and upper portions of trees, leading to increased clearing formation and deadwood habitat with impact on the structure of woodland and value of timber crops. However, the creation of gaps leads to more structural and subsequent biodiversity variation and increased heterogeneity, which is likely to be beneficial for biodiversity interests. Stands of woodland damaged by the 1987 storm in south east England were found to have increased biodiversity in 2001 (Kirby *et al.*, 2005). Large-scale damage could threaten the ability of the woodland to recover as a sheltered woodland environment is replaced by exposure, increased possibility of erosion of soils and susceptibility to drought.

Interactions with other factors. Climate change could interact with most other influences on woodland biodiversity, particularly in causing threatened species to become locally extinct. An important interaction is between climate change and tropospheric ozone levels, which are highest in warm dry conditions and predicted to increase (NEG-TAP, 2001). This is an area requiring further study. Rising carbon dioxide levels are also important (Broadmeadow, 2002), through having a fertilising affect on growth (providing other factors, such as nitrogen supply are not limiting) and reducing water lost for the same uptake of carbon improving water use efficiency.

3.3.5 *Summary: woodland and forestry*

- **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

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Table 3.6 Summarising direct effects of climate change on habitats in the woodland and forestry sector

Climate Change	Broad-leaved mixed and Yew woodland (Broad habitat)	Coniferous Woodland
Increased summer temperature	Potential introduction of new pest species from warmer climates may present threat to tree species and hence change character of habitat	
Increased winter temperature	Increased threat to tree species from pests and diseases over-wintering where they would not previously have done so.	
Summer drought	<p>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).</p> <p>Increased risk of forest fire destroying habitat</p>	<p>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>).</p>
Sea level rise	Potential loss of low-lying coastal woodlands.	
Increased flooding	Wet woodland may expand as a result of planting or abandonment of particularly flood prone agricultural areas	
Increased frequency of extreme events	An increase in windthrow is likely, leading to an increase in gaps in woodland and deadwood.	An increase in windthrow is likely, leading to an increase in gaps in woodland and deadwood.

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Table 3.7 Summarising effects of climate change on ecosystem function and species in the woodland and forestry sector

Climate Change	Ecosystem function	Species
Increased summer Temperature	Potential increase in productivity (and carbon sequestration), but likely to be outweighed by reductions in summer rainfall, at least in the south east.	Colonisation of invertebrate species from southern Europe may enrich biodiversity. Southern species may extend northwards (e.g. speckled wood butterfly)
Increased winter temperature	Increase in soil respiration would tend to increase release of carbon dioxide from soils	Species currently limited by low winter temperatures may extend their range
Earlier spring	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 populations of drought sensitive species – both of trees and other types of organism e.g. speckled wood butterfly.
Increased summer drought	Decrease in productivity and carbon sequestration especially in south and east.	
Wetter winters	May partially offset effects of drier summers by increasing ground water levels at the start of the summer.	
Increased flooding	Limited evidence that floodplain woodlands may reduce impact of flood events	
Increased frequency of extreme events		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.

3.4 Towns, cities and development

3.4.1 Context

Towns and cities are controlled environments focused on the needs of people, but offering opportunities and active support to many other species. There is a significant diversity of wildlife in cities, despite the level of modification and level of human activity (e.g. Hill *et al.*, 2001, Henderson 2003, McKinney 2006). The species present in towns and cities include introduced, invasive and native species.

The proportion of urban land cover in England is estimated at 10.6% in 1991 - up-to-date statistics for land use cover are not available, but the government's policy target that 60% of all new homes should be built on previously developed land has been exceeded (ODPM 2005a). Rapid development has nevertheless occurred in many parts of England recently. The Countryside Quality Counts project (<http://www.cqc.org.uk/index.html>) has established a database to assess how the character areas of England are changing as a result of development and other pressures and what change means in terms of maintaining local distinctiveness. Results from assessment of the period 1990-1998 show that landscape quality in the many areas, such as Bristol and Birmingham have changed (Figure 3.2) and the reporting indicates that this was largely due to development.

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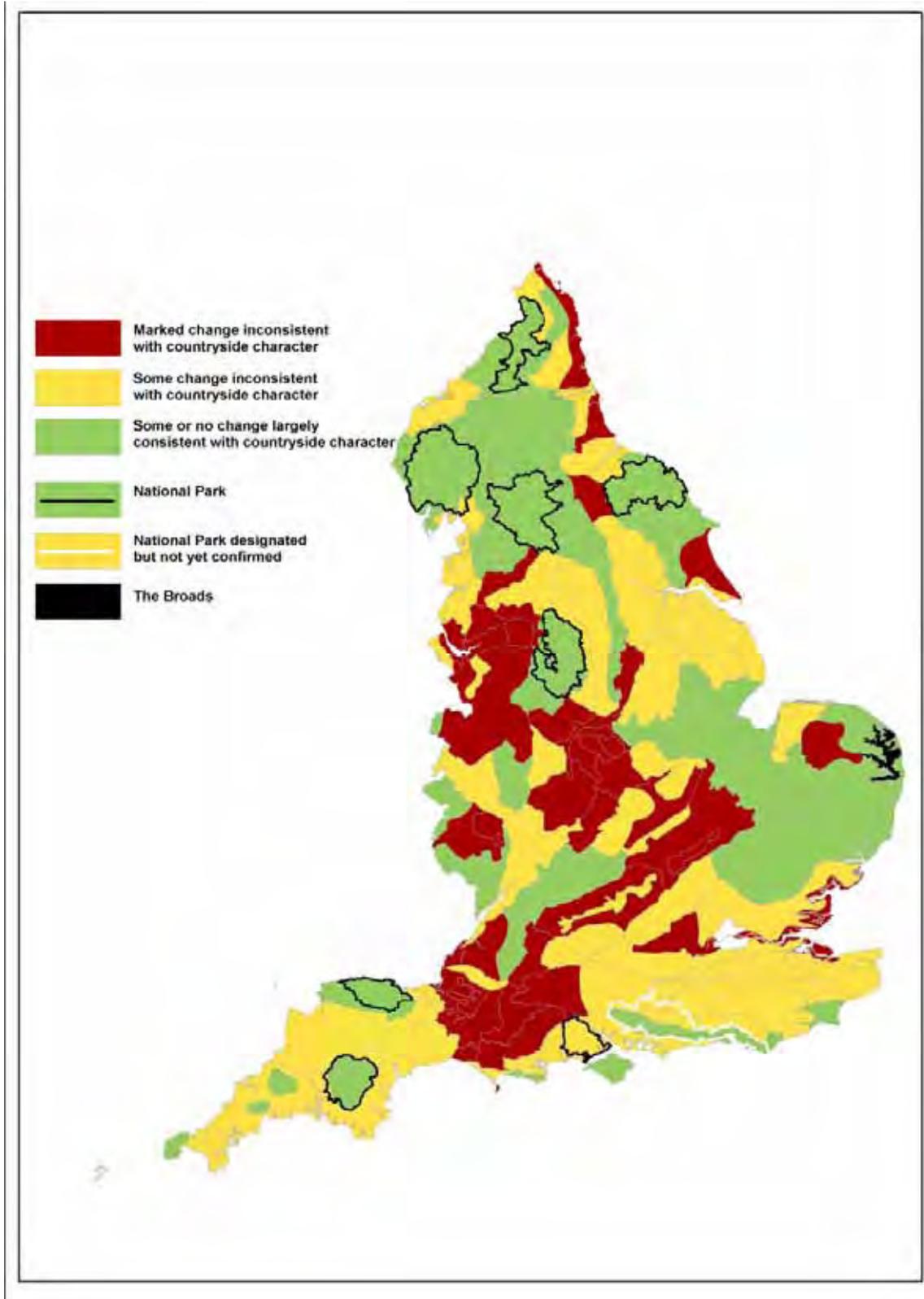


Figure 3.2 Countryside Quality Counts Indicator for the period 1990-1998 (Source <http://cqc.org.uk/publications/CQC-Indicator-Map.pdf>)

The array of expected climate impacts upon towns and cities chiefly concern temperature and precipitation and the interaction between them. The impacts are

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largely due to responses to an already harsh environment where the hard infrastructure will exacerbate heat effects, drought and flooding. Many towns and cities are located in river valleys and fluvial flood-plains. Many are also located in low-lying coastal areas which may also be affected by sea-level rise and storm surge, leading to contamination, loss or conversion of coastal habitats.

Biodiversity in developed areas. Habitats within towns and cities range from the pockets of semi-natural areas, where there is limited intervention, to the most highly managed areas. Habitat fragmentation is extreme in towns and cities, though some semi-natural corridors (e.g. river corridors) remain of value to wildlife (Angold *et al. in press*). Broad Habitats in towns and cities listed in the UKBAP include built-up areas and gardens, improved grassland (i.e. as amenity grassland), water and wetland areas (river and stream corridors, standing open water and canals and reedbeds) as well as ancient and/or species-rich hedgerows. Priority Habitats in towns and cities include patches of lowland meadows (e.g. on floodplains), ancient or semi-natural woodland, lowland beech, yew woodlands and mudflats. Other open areas may also be important for wildlife. These include brownfield areas (including old industrial ponds and dock areas), sports fields, community greens, cemeteries and churchyards, and linear corridors and ancillary areas occupied by road and rail where verges provide habitat space (Helden and Leather, 2004; Pauleit *et al.*, 2005).

Buildings also provide habitats for some species but the development of towns, cities and associated infrastructure is also the cause of significant fragmentation of more extensive adjacent habitats (e.g. heathlands).

Species identified in *Working with the Grain of Nature* (Defra, 2002a) as of particular importance for biodiversity in towns and cities are stag beetle (*Lucanus cervus*), great crested newt (*Triturus cristatus*), song thrush (*Turdus philomelos*), water vole (*Arvicola terrestris*) and bats. Some species noted in the EBS as living successfully in urban/suburban areas are: black redstart (*Phoenicurus ochruros*), grey heron (*Ardea cinerea*), great spotted woodpecker (*Dendrocopos major*), common frog (*Rana temporaria*), and a range of fish species, whilst other valued species, including rook (*Corvus frugilegus*) and hedgehog (*Erinaceus europaeus*), are identified as declining or have disappeared.

Urban conditions and climate change. In the urban environment, climate change will have a similar range of effects such as increased temperature, changes in seasonal rainfall patterns and increase in storm frequency, but conditions will also differ to those found in the wider landscape because of the concentration of hard infrastructure (buildings and impermeable paving) and high levels of anthropogenic activity.

The hard infrastructure acts as heat absorbing surfaces, trapping heat during the day, which is released during the night. This leads to localised increases in air temperature otherwise known as a 'heat island effect'. Within built-up areas, this exacerbates the effects of increasing summer temperatures by several degrees relative to rural locations. Hunt (2004) quotes an additional 4°C for London.

Temperature increase and an increase in the number of sunny days during summer could result in the heat island effect causing heat stress potentially causing mortality

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in plants and animals. The extent and frequency of the heat island effect is expected to increase with climate change (Rosensweig *et al.*, 2005; Shackley *et al.*, 1998).

The direct effect of high summer temperatures and drought in urban areas will be accentuated by air quality impacts on biodiversity, particularly exacerbation of ozone during stagnant summer cyclones. This may have an adverse effect on urban trees and vegetation (LCCP, 2002; Stone, 2005).

Hard infrastructure also provides opportunities for biodiversity. For example, towns provide shelter from strong winds and extreme cold for roosting over-wintering birds and habitat for some species that are able to exploit urban conditions, such as peregrines nesting on building ledges and hunting pigeons.

Hard infrastructure includes impermeable pavements or areas where the soil is sealed and this prevents percolation of rainwater. When combined with more intense rainfall events, impermeable surfaces will contribute to urban flooding with further potential adverse effects for biodiversity via contamination of habitats by combined sewer and road drainage overflow (SEPA and partners, 2000). (See also Section 3.4.2.) Impermeable surfaces also restrict water supply to plants, which may become increasingly water-stressed during drought and this will be exacerbated by the heat island effect.

Hard infrastructure includes coastal and riverside development which will be affected by sea level rise and storm surge similar to the effects for other coastal areas (Hampshire County Council, 2003). (Coastal biodiversity impacts are discussed in Section 3.5.)

3.4.2 *Terrestrial habitats*

Direct impacts of climate change on urban terrestrial broad and priority habitats will largely be the same as for the other sectors: but may be exacerbated by the heat island effect. Some habitats and features are specific to urban environments.

Parks and gardens are extensive managed spaces: Bisgrove and Hadley (2002) quote estimates of 2,500 public parks and gardens and designed landscapes of historic interest in addition to 25,000 recreational open spaces, and LCCP (2002) states that gardens and parks account for approximately 20% of Greater London. Direct impacts of climate change are those associated with increased temperatures, drought, prolonged growing season and damage to vegetation caused by extreme events. Water and soil management are seen as inextricably linked in any practice to protect gardens from adverse climate change impacts. The National Trust reports that it already is changing its management practices in response to longer growing periods, and more extreme weather events, with consequent impact on biodiversity (National Trust, 2005). Impacts of climate change upon gardens and gardening include accelerated loss/oxidation of soil organic matter, leading to loss of structure and release of nutrients, and effects on water relations and water use (Bisgrove and Hadley, 2002),

The characteristic English lawn is considered very likely to be adversely affected by climate change, though more natural meadow communities will be more resistant

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(Bisgrove and Hadley, 2002). Grass productivity is greatly reduced during hotter, drier summers (Sparks and Potts, 1999). These factors may support the trend towards urban creep and replacement of lawns with impermeable surfaces. The replacement of permeable soil with hard surfaces reduces invertebrate populations and bird feeding habitat (Pauleit *et al.*, 2005).

English gardens contain both native and non-native plant species each with a range of vulnerabilities and responses to climate change. The smaller size and shorter lifespan of shrubs may mean that some are less affected by climate change (Bisgrove and Hadley, 2002). The provenance of plants is important in determining their response to climate change impacts; opportunities exist for appropriate selection and change. People's gardening preferences and species selection may change and this could affect species that are dependent on current gardening practices, such as nectar feeding invertebrates and predators such as garden birds and amphibians. Although the change in gardening preferences is an indirect impact of climate change, the susceptibility of current garden plants could lead to change in distribution and community structure in towns and cities.

Trees. It is thought that urban woodland, garden and street trees may provide an early indication of adverse impacts of climate change in the challenging urban environment (Broadmeadow, 2004). They are vulnerable to root damage (suffocation, drowning) and to wind throw in storms or fire during dry periods. Beech (*Fagus sylvatica*) is seen as a species particularly vulnerable to climate change. Broadmeadow (2004) notes evidence that Fomes root rot (*Heterobasidion annosum*), which affects conifers, may be greater at higher temperatures, and in drier conditions.

Direct climate change effects on trees and woodlands include potentially increased growth rates with raised CO₂, phenological change with increased temperatures, stability changes and drought stress as a result of changed rainfall patterns, and increased storm damage. There is also increased likelihood of fire in drought periods.

There may be a shift in typical urban communities, especially an increase in pest and diseases organisms that thrive under climate change. There is a greater susceptibility of stressed trees to pests and disease and there are uncertainties surrounding responses to other climatic conditions (Broadmeadow and Ray, 2005).

Climate change may exacerbate the effects of air pollution and water stress, which have been recognised as important in tree health, leading to reduction of crown density, with potential impacts for both the trees and the biodiversity dependent upon them (Ashmore *et al.*, 1985).

3.4.3 *Freshwater habitats*

Many towns and cities are built on rivers or flood plains, which are highly managed, with controls over water levels, but they will be susceptible to climate change induced effects of low flows and flash flooding with consequences on any habitat they support.

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Freshwater habitats in urban settings will be susceptible to impacts described for the Water and Wetland sector, but in the urban environment these will interact with the effects of hard, impermeable surface area (hard-standing, road, buildings and decks). This lead to loss of habitat and together with compaction of soils reduced permeability to precipitation and reduced infiltration (London Assembly, 2005; RHS, 2005b). This could increase the problems associated with flooding or increased drought stress. The heat island effect will increase water demand by plants and animals and increase evapotranspiration.

LCCP (2002) identifies climate change impacts across biodiversity in freshwater and wetlands, intertidal and estuarine areas, and terrestrial environments (including gardens), in London. LCCP (2002) points to the importance of river corridors and wetlands to nature conservation across London, and the impact of effects such as changes in river flow regimes, water temperature and water quality in affecting the survival, spawning times, reproductive success and growth of invertebrates, freshwater fish and amphibians (Beebee, 1995; Cox, 2000).

3.4.4 *Inter-tidal and coastal habitats*

The diverse and highly productive environments of inter-tidal/estuarine zones are strongly affected by the design and location of flood defences. Impacts upon London's inter-tidal habitats (LCCP, 2002) are expected to be associated with increased inundation and storm flooding, faster coastal erosion, sea water intrusion into freshwater tributaries during storms, changes to tidal conditions and sediment supply (erosion/accretion) as well as direct effects (air temperature and rainfall) affecting saltmarsh plants. This will have further impacts on sedimentation (LCCP, 2002). These impacts are similar to impacts at non-urban sites, but close to towns and cities intertidal habitats are at particular risk as a consequence of the flushing of storm sewage if sewers are overwhelmed during intense summer storms. Although such storms may become less frequent, UKCIP scenarios acknowledge uncertainty in this variable. The urban flooding which resulted from intense rainfall in London in August 2004 and which led to raw sewage flooding the tidal Thames had serious impacts on fish stocks (Environment Agency, 2005). Impacts upon inter-tidal and coastal habitats are also a consequence of built development encroaching onto the foreshore and "coastal squeeze" between defences and open water (Nicholls and Branson, 1998).

3.4.5 *Impacts of climate change on species*

There is no specific literature providing evidence of direct impacts of climate change on species in urban areas.

There may be a shift in urban communities through increases in non-natives, escaping from gardens. Hill *et al.* (1994) emphasise that many alien species commonly cultivated in gardens are likely to increase in England. In addition, native opportunist species or weeds of gardens and wasteland may increase. These species are unlikely to encounter dispersal difficulties because gardens are widespread and they may attain a competitive advantage against native species. The spread of exotic plant species from gardens could be facilitated by warmer

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temperatures, changes in precipitation and high CO₂ levels (Dukes and Mooney, 1999).

3.4.6 *Summary: towns, cities and development*

It is difficult to untangle direct and indirect climate change impacts and interactions in urban and development areas, especially as habitats and species are already strongly affected by human impacts. The direct impacts on urban habitats and species are likely to be very similar to those in the wider landscape but hard and impermeable surfaces will exacerbate the effects of increased temperature and changes in rainfall, as exemplified by the urban heat island effect.

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Table 3.8 Summarising direct effects of climate change on habitats of towns, cities and development (TCD) sector

Climate Change	Semi-natural habitats in TCD (low levels of management)	Intensively managed habitats (e.g. parks, gardens, landscaped business parks)	Wetlands and water bodies in TCD	Built environment (buildings, infrastructure)
Increased summer temperature	Drying, risk to native species. Increased likelihood of non-native species invading/becoming established and changing species balance	Drying, soil exposure and erosion, invasion/introduction of non-native species. Deteriorating air quality – impacts for stressed species Increased stress for trees	Poor oxygenation and poorer conditions for flora and fauna.	Hotter drier conditions in buildings may affect habitats living in/on roofs and walls (lichens, bats, etc.)
Increased winter temperature	Over-wintering by pest species leading to build up affecting flora. Introduction and establishment of non-native species affecting species balance	Changing faunal behaviour with potential for loss in sudden cooler periods. Longer grass growth through winter, Availability of prey species less predictable.	Potential changes in species balance with introduction/invasion on non-native species	Over-wintering by insects, birds may change food availability and ecosystems
Earlier spring	Risk of disjunction between predator and prey species leading to loss of native insects, invertebrates, birds and ecosystem change	Disjunction in phenology with changes to ecosystem balance. Possible loss of ornamentals in sudden cold snaps	No information	No information
Summer drought	Habitats at risk of drying and burning and consequent losses. Combined with recreation pressure, damage and erosion to surfaces with impacts for infiltration, surface cover	Risk of conversion of green areas to hard surface and therefore intensification of drought conditions for plants. Subsidence – tree root damage Changes in soil microbiological activity with potential impacts for nutrients and flora	Low water levels – loss of habitat quality. Risk of contamination and loss of species	Infrastructure corridors: loss of habitats, risk of fire. Desiccation of green spaces; changes in species balance

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Climate Change	Semi-natural habitats in TCD (low levels of management)	Intensively managed habitats (e.g. parks, gardens, landscaped business parks)	Wetlands and water bodies in TCD	Built environment (buildings, infrastructure)
Wetter winters	Changed conditions for soil fauna, with impacts for nutrients and flora	Changes in soil microbiological activity with potential impacts for nutrients and flora	No information	Mould growth within buildings
Sea level rise	Loss of fringing marsh, exposure of coastal habitats to flood risk	Loss of managed habitats close to coast. Change in soil conditions and ecosystems leading to changed flora	Salinization of wetland habitats and natural water bodies , with consequent change of species at coast	Loss of built environment habitats at coast but deterioration of some coastal buildings providing new habitats
Increased flooding	Increased risk of contamination and loss of habitats in some circumstances	Provision of new drainage structures further depleting groundwater recharge and intensifying drought Erosion of disturbed areas	Potentially greater likelihood of contamination of habitats (overtopped sewers, storm run-off) with impacts for fish, invertebrates, etc.	Temporary/permanent loss of habitats within/under buildings; contamination of such habitats
Increased frequency of extreme events	Increased risk of wind-throw in extreme conditions.	Storminess: Potential loss of mature trees	No information	Risk of tree loss/pre-emptive cutting along infrastructure corridors (e.g. adjacent to rail or road). Likelihood of changes in species planted, towards more wind resistant species (smaller, shorter-lived trees).

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Table 3.9 Summarising effects of climate change on ecosystem function and species in the towns, cities and development sector

Climate Change	Ecosystem function	Species
Increased summer Temperature	Nutrient recycling: increased whilst water is available Decomposition: faster Biomass production: faster whilst water is available Regulation (water): more difficult Erosion control: risk of deterioration	Risk to species at the limit of their range; faster growth for some introduced species. Increased planting of non-native species and risk of invasion.
Increased winter temperature	Nutrient recycling: increased whilst water is available Decomposition: faster Biomass production: continues for longer Regulation (water): unchanged/improved Erosion control:	Failure to hibernate (hedgehogs, invertebrates) with risk of starvation if food availability is not improved
Earlier spring	Nutrient recycling: increased Decomposition: faster Biomass production: faster whilst water is available Regulation (water): no information Erosion control: improved when cover us re-established	Birds: possibility of increased number of broods but lack of synchronicity with prey species may affect viability.
Increased summer drought	Nutrient recycling: declining Decomposition: declining Biomass production: declining Regulation (water): declining Erosion control: risk of deterioration	Risk of loss of aquatic/wetland species and species at limit of their range
Wetter winters	Nutrient recycling: increased whilst water is available Decomposition: change depends on local conditions Biomass production: unchanged Regulation (water): unchanged Erosion control: risk of deterioration	No information

3.5 Coast and sea habitats and biodiversity

3.5.1 Context

Coasts and seas comprise a range of habitats: coastal saltmarsh, estuarine mudflats sand dunes, sandy beaches, rocky shores, eelgrass beds in the shallow subtidal and oceanic seas (UKBAP, 2005; Defra, 2002a, 2003). Some of these habitats and the species they host are of economic importance and others are considered high priority for conservation action (UKBAP, 2005). The principal effects of climate change on coasts and seas can be broadly divided into three categories. Firstly, sea-level rise and an increase in the frequency of storm-surges are likely to lead to loss of coastal habitats, increased variation in salinity conditions and loss and changes of some habitat as a result of sea defence development resulting from sea-defence development. Secondly, temperature changes caused partly by a general trend towards warmer conditions, but also by intensification of the North Atlantic Oscillation and associated shifts in ocean currents, are likely to lead to changes in the distribution, abundance and survival of species and modify the structure and composition of habitats. Lastly, changes in ocean chemistry, primarily increasing CO₂ concentrations and resultant decreases in pH and the saturation rate of calcium carbonate are likely to affect the metabolism, skeletal structure and survival of some organisms (Robinson *et al.*, 2005).

3.5.2 Effects on habitats

Several types of low-lying coastal habitats, but notably coastal grazing marsh, saline lagoons and saltmarsh are likely to be adversely affected by inundation. Saltwater flooding poses a significant threat to these habitats as many of their associated flora and fauna tolerate a finite range in salinity or flooding conditions (Olf *et al.*, 1988; Boorman, 1992). The morphology of estuaries is likely to alter substantially, particularly in the south-east of England. In general, it is predicted that more extensive mudflats will become sandier, which may benefit bird species such as oystercatcher (*Haematopus ostralagus*), but adversely affect others such as redshank (*Tringa totanus*) and dunlin (*Calidris alpina*) (Harrison, Berry and Dawson, 2002; Austin and Rehfish, 2003).

Erosion of habitats is also likely to be exacerbated by sea level rise and increased storminess, particularly where coastal defence structures prevent landward movement of habitats, leading to 'coastal squeeze' (Covey and Laffoley, 2002). Saltmarsh, but also priority habitats such as sand dunes, coastal vegetated shingle and mudflats (UKBAP, 2005) are likely to be the most adversely affected. In SE England, coastal erosion was responsible for a 20% reduction of the saltmarsh resource between 1973 and 1988 and in the whole of England, a loss of 8,000-10,000 ha of intertidal mudflat by 2013 is predicted (UKBAP, 2005). Sandy beaches are also likely to suffer from increased erosion in response to climate factors such as the potential increase in the number and severity of storms (Brown and McLachlan, 2002).

The loss of saltmarsh is of concern as they form the base of estuarine food webs, supplying large amounts of organic material to adjacent habitats, particularly to mudflats (Hughes, 2004). Although sea-level rise will generally result in loss of

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habitat, some loss of saltmarsh and lagoon habitat could be offset by the natural creation of new habitats provided that coastal realignment is not prevented by hard sea-defences. In such instances, realignment could lead to loss of other habitats further inland, but these are mostly likely to be of lower conservation priority. In contrast, flood defence works have the effect of exacerbating habitat loss by resulting in 'coastal-squeeze' (Hiscock *et al.*, 2005). The addition of flood defences also significantly modify the existing habitats into which they are placed (Airoldi *et al.*, 2005; Martin *et al.*, 2005; Moschella *et al.*, 2005).

The addition of coastal defence structures also means that there is an increase in hard habitats (which effectively act as artificial rock shores) at the expense of soft habitats around the coastline. Rocky shores are, therefore, fairly unique in that more coastal defences reduces the fragmented nature of this habitat leading to greater connectivity (Thompson, Crowe and Hawkins, 2002). Increasing severity and frequency of storms will increase erosion of rocky shores that are predominantly chalk or other material more prone to erosion (Harrison, Berry and Dawson, 2002). In the subtidal region, eelgrass beds, which are a UKBAP high priority habitat and likely to be proposed as an Annex 1 species under the Habitats Directive (UKBAP, 2006) may be affected by increased storminess and temperature. An increase in storminess will increase erosion of seagrass beds (Davison and Hughes, 1998). Seagrass beds in England underwent a significant decline during the warming period of the 1930s leading to concern over the predicted increase in sea surface temperature in the future.

Changes in water temperature and chemistry, and changes in ocean currents are likely to affect individual species associated with specific habitat types. In some instances the effects of such changes can be sufficient to significantly alter the community composition and structure of habitats. For example, sea-surface temperature changes in the North Sea between 1958 and 2002 have resulted in asynchrony in the timing of planktonic peaks and large changes in pelagic community compositions (Beaugrand *et al.*, 2002; Edwards and Richardson, 2004).

Fish communities are also changing due to the increasing prevalence of exotic, southern species. This has been well documented, particularly for the waters off SW England (Genner *et al.*, 2004) and the North Sea (Beare *et al.*, 2004).

Warming temperatures are likely to result in increased stratification of surface waters. This is likely to have a considerable impact on ocean productivity, with knock on effects at all trophic levels (McGowan, Cayan and Dorman, 1998). Ocean stratification affects marine productivity by reducing the upwelling of nutrients and by affecting the length of the growing season. These mechanisms oppose each other, so predicting the effects of stratification in UK waters is problematic (Le Quéré *et al.*, 2003). In other parts of the world, such as in the northwest Pacific, such changes have resulted in the substantial ecosystem changes, epitomized by the catastrophic decline by more than 90% of apex predators (Viet *et al.*, 1997, McGowan, Cayan and Dorman, 1998).

Since it is surface waters (generally those above the permanent thermocline at about 200 m depth) that will experience temperature rises in the near future, deep water coral reefs, notably those dominated by scleractinian coral (*Lophelia pertusa*) are

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unlikely to undergo significant changes. The growth rate of corals and other reef organisms is affected by the saturation state of calcium carbonate in water, and hence CO₂ concentrations (McNeil *et al.*, 2004, Orr *et al.*, 2005). Whilst the majority of evidence comes from tropical coral reefs, there is no reason to suppose that temperate coral communities will not also be affected.

3.5.3 *The impact of climate change on species*

Observed climate change has already affected the distribution of many species in the UK and elsewhere (Thomas *et al.*, 2004). In the North Sea, for example, the distributions of both commercial and non-exploited fish have responded markedly to recent increases in sea temperature, with nearly two-thirds of species shifting in mean latitude, depth or both over 25 years (Perry *et al.*, 2005) and similar changes have occurred in southwest England (Genner *et al.*, 2004). Historical fluctuations are known to have occurred in herring and pilchard (sardine) populations in the English Channel in response to climate (Hawkins *et al.*, 2003; Southward *et al.*, 2004) and estuarine fish populations in the Thames Estuary have been shown to be strongly affected by climatic variability (Attrill and Power, 2002).

Distributions of wintering birds have also changed in response to warmer temperatures. The majority of species of wader that over-winter in internationally important numbers on UK estuaries have moved their range in a north-easterly direction due to recent climate change (Austin and Rehfisch, 2005) (Figure 3.3). Further shifts are predicted (MONARCH: Berry *et al.*, 2005) and similar responses are expected for waders on non-estuarine coasts (Rehfisch *et al.*, 2004).

A movement northwards and eastwards of many benthic marine organisms is also expected, particularly those near the geographic limits of their distribution (Hiscock *et al.*, 2004; Kendall *et al.*, 2004) and has already been observed in some intertidal species (the MarClim programme: www.mba.ac.uk/marclim; Herbert *et al.*, 2003). Northern species are getting rarer (e.g. *Semibalanus balanoides* and *Patella vulgata*); these are often faster growing and more productive than southern species (Southward, 1991; Southward *et al.*, 1995).

Increasing temperatures due to climate change are thought to be an important factor in facilitating the arrival and establishment of non-native species (Elliot, 2006). Examples include the leathery sea squirt (*Styela clava*), which is inhibited by the minimum temperature required for spawning (Eno, Clark and Sanderson, 1997) and the slipper limpet (*Crepidula fornicata*) which may also be limited by minimum winter temperatures and therefore be expected to increase in the future (Minchin, McGrath and Duggan, 1995). A rapid spread in introduced bivalves such as Pacific oysters (*Crassostrea gigas*) is also expected (the MarClim programme: www.mba.ac.uk/marclim). Of particular concern are notorious invasive species such as the Northern Pacific sea star (*Asterias amurensis*), caulerpa seaweed (*Caulerpa taxifolia*), and the American comb jelly (*Mnemiopsis leidyi*).

It has been noted that monitoring and contingency plans must be put in place for future invaders (Elliot, 2006). It should also be noted that whilst species are expected to extend their ranges in response to warming temperatures, the degree to which they can do so is dependent on the availability of suitable habitat to move in to.

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Sea defences are likely to act as stepping stones for rocky shore species, enabling spread across unfavourable habitat patches (e.g. MarClim team and Hawkins, unpublished). These structures may also facilitate the spread of non-native species.

Other species directly affected by climate change include the phytoplankton species (mainly dinoflagellates) that are linked with Harmful Algal Blooms (HABs). Climate variability and regional climate warming appear to play a dominant role in HAB occurrence due to the strong link between the increased abundance of dinoflagellates and decrease in diatoms, which is linked to temperature increase as well as indirect effects linked to the occurrence of stratification (Edwards *et al.*, 2006). Although the links with anthropogenic nutrient input are well studied, research into climate models linked to HABs is still at an early stage (Reid, 2006).

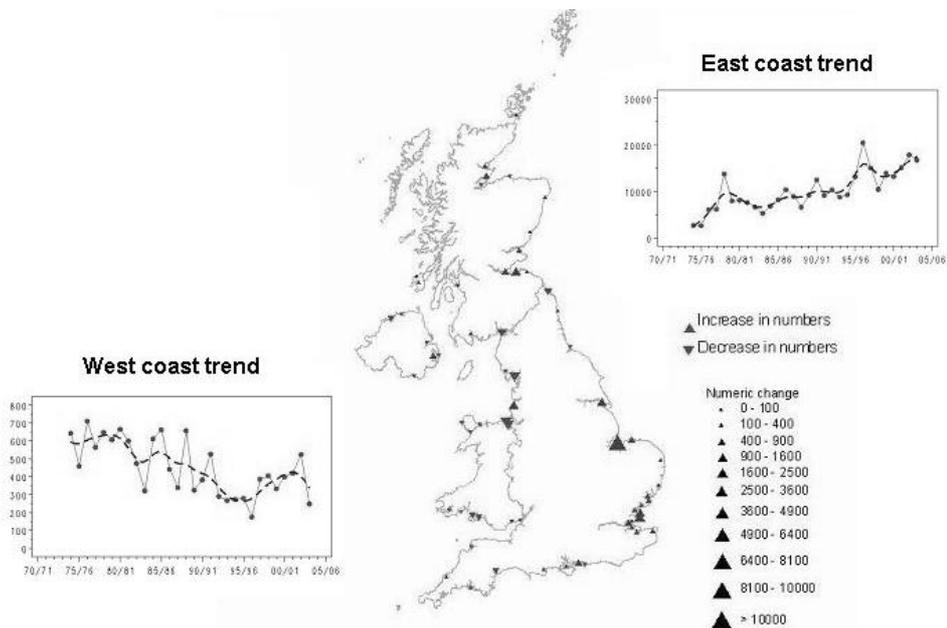


Figure 3.2 Distributional changes of Bar-tailed Godwit (*Limosa lapponica*) between 1978 and 2003. Source: Maclean *et al.*, (2005).

There is also concern regarding the possibility that as climate warms, the abundance and productivity of brown algae will decrease as there are latitudinal gradients in the northeast Atlantic, with fucoid dominated shores giving way to barnacle dominated shores further south. Brown algal growth is inhibited by hot summers (Thompson *et al.*, 2004). This is likely to have two significant effects on other species. First, it would represent a loss of potentially rich feeding grounds for species such as Turnstone (*Arenaria interpres*) that feed on small easily desiccated invertebrates living on or below exposed seaweed. Secondly, as algae die or are broken away, the resulting debris is exported to sediment habitats where it considerably boosts *in situ* production of bacteria at the base of the food web (Kendall *et al.*, 2004). An increase in sea-level will also have a major impact on the amount of habitat available for rocky shore invertebrate communities where shore topography prevents the upward migration of biota. Where a seawall limits shores, for example, biological production will be curtailed as the area available for colonisation decreases (Kendall *et al.*, 2004).

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For many marine species, changes in distribution and abundance are likely to be further affected by the intensification of the North Atlantic Oscillation system and concomitant changes in water masses and the location of productive up-welling zones, such as occur at the edge of the continental shelf to the southwest of England (Bakun, 1990, Blenckner and Hillebrand, 2002, Grantham *et al.*, 2004).

The timing of marine 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 (Sims *et al.*, 2001). Flounder have been shown to migrate earlier in NAO positive winters (Sims *et al.*, 2004), which are now less frequent. A growing body of evidence suggests that such advances in activity can lead to loss of synchrony between requirements and availability of resources (Crick, 2004). For example, plankton production is highly temperature dependent (Edwards and Richardson, 2004). The differences in response vary considerably between pelagic assemblages and have led to a mismatch between successive trophic levels and as a result, to large declines in the abundance of species at higher trophic levels, such as salmon (*Salmo salar*) (Beaugrand and Reid, 2003) and seabirds (Thompson and Ollason, 2001). The major changes occurring in phenology could be important for ecosystem function, as effects can be observed at a number of trophic levels (Edwards and Richardson, 2004).

Sea-level rise and increases in the frequency of storm surges are also likely to have an adverse affect on species, by changing salinity regimes, causing habitat loss or by increasing mortality directly. Amongst the worst affected by inundation will be species associated with saline lagoons (Bamber and Barnes, 1998; Stewart, 2001). Species nesting in low lying areas, such as roseate tern (*Sterna dougallii*), are likely to be amongst the worst affected directly by sea-level rise as a consequence of nest flooding (Robinson *et al.*, 2005). Birds are also likely to be amongst the most threatened by habitat loss. Waders, are vulnerable to expected reductions in the area of suitable habitat for breeding and feeding (Smart and Gill 2003; Austin and Rehfish, 2003; Rehfish *et al.*, 2004b; Rehfish and Austin, in press). A reduction in the number of seal "haul out" sites used for breeding, nurseries and resting is also expected (Robinson *et al.*, 2005).

Increased oceanic CO₂ is already having a significant impact on ocean chemistry and thus on ocean-dwelling species (Orr *et al.*, 2005). Acidity changes are most likely to have a direct impact on species with high metabolic rates and pH-sensitive blood oxygen transport such as ommastrephid squid (Robinson *et al.*, 2005). Decreases in the availability of carbonates (caused by increased acidity) are already adversely affecting calcifying organisms such as molluscs, corals and some plankton (Olf *et al.*, 1988). Acidification of the ocean is directly linked to increasing CO₂ in the atmosphere rather than climate change per se, although increased CO₂ is also a cause of climate change (German Advisory Council on Global Change (WGBU). 2006). More research is required as the combined affects of ocean acidification and climate change have not yet been addressed (Turley, 2006).

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3.5.4 *Summary: coasts and seas*

- **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 of England 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 saltmarsh and mudflats have been lost or are at risk due to sea level rise.

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Table 3.10 Summarising direct effects of climate change on habitats of the coasts and seas sector

Climate Change	Saltmarsh and/or coastal grassland	Estuaries	Saline lagoons	Opens seas	Other habitats
Increased summer temperature	Increased evaporation may lead to drying up of coastal grazing marsh	Northward shift in intertidal organisms	Increased evaporation will lead to hypersaline conditions in summer	Major changes in phytoplankton community with knock-on effects for species at higher trophic levels. Increased occurrence of sub-tropical species.	Northward shift of benthic marine organisms on rocky shores
Increased winter temperature	No major changes documented, but north-easterly shift in associated species likely	Increased proportion of UK over-wintering population of waders over-wintering on east coast estuaries	No major changes likely	Increased occurrence of species associated with lower latitudes.	North-easterly shift of benthic marine organisms on rocky shores
Earlier spring	Earlier onset of breeding. Possible phenotypic mistiming with invertebrate prey	No major changes documented, but phenological advancement likely	No major changes documented, but some phenological advancement likely	Earlier hatching and faster embryonic development and growth of marine organisms	No major changes documented, but earlier arrival of migratory species anticipated
Summer drought	Drying up of coastal grazing marsh.	No major changes documented, but higher nutrient levels and lower oxygen levels anticipated	Lower rainfall will lead to hypersaline conditions in summer	No major changes documented.	No major changes documented but less fucoids likely on rocky shores
Wetter winters	Flooding of coastal grazing marshes	No major changes documented, but lower salinity expected.	Increased freshwater input likely to lead to low-saline conditions in winter	No major changes documented.	Increased erosion of coastal cliffs.
Sea level rise	Inundation of coastal grazing marsh and saltmarsh. Loss of the latter predicted to be as much as 10,000 ha by 2013.	Change in morphology. In general large mudflats are expected to become sandier.	Increased saltwater input during the winter will lead to changes in salinity regimes.	No major changes expected. Slight landward movement of benthic organisms possible	Increased erosion of coastal cliffs, sand dunes and other habitats
Increased CO ₂ concentrations	Decreased abundance of calcifying organisms	Decreased abundance of calcifying organisms	No major changes anticipated	Decreased abundance of calcifying organisms and species with pH sensitive blood	Reduction in growth rate of scleractinian corals

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Climate Change	Saltmarsh and/or coastal grassland	Estuaries	Saline lagoons	Opens seas	Other habitats
Changes in upwelling zones and increased stratification	No major changes anticipated.	No major changes anticipated.	No major changes anticipated.	Major reduction in ocean productivity with associated effects on almost all marine species	No major changes anticipated but Likely to influence recruitment regimes of benthic animals.
Increased flooding	More variable water-levels resulting in increased stress on many plant species and potential flooding of bird nests	Periodic influx of freshwater with poorly documented consequences	Periodic influx of freshwater, leading to more variable salinity conditions.	No major changes anticipated.	Increased erosion of coastal cliffs
Increased frequency of extreme events	Increased erosion	Morphological changes	Increased flooding with saltwater	No major changes documented, but changes in dispersal patterns of pelagic organisms likely	Increased erosion of coastal cliffs

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Table 3.11 Summarising effects of climate change on ecosystem functioning and species in the coasts and seas sector

Climate Change	Ecosystem function	Species
Increased summer Temperature	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.	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>).
Increased winter temperature	Poorly documented, but variable north-easterly changes in the distribution of organisms are likely to affect the ways in which species interact.	North-easterly range extension of non-estuarine waders. Higher proportion of estuarine waders over-wintering on the east coast.
Earlier spring	Poorly documented, but variable advancement in phenology likely to change ways in which species interact.	Earlier hatching and faster embryonic development and growth of squid. Earlier egg-laying of waders
Increased summer drought	Changes in nutrient cycling, community composition and productivity of coastal grazing marsh anticipated	Reduction in food availability for waders
Wetter winters	Changes in nutrient cycling, community composition and productivity of coastal grazing marsh anticipated	Higher stress for species associated with saline and brackish lagoons due to more variable salinity regimes.
Sea level rise	Reduction in organic input to estuarine habitats, due to loss of saltmarsh likely to have a major impact on food webs.	Loss of seal haul out sites, nest flooding of roseate terns (<i>Sterna dougalli</i>)
Increased CO ₂ concentrations	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.	Reduction in abundance and growth of calcifying organisms. Increased mortality of pH sensitive species such as squid.
Changes in upwelling zones and increased stratification	Increased ocean stratification likely to have a major impact on the functioning of marine habitats, with catastrophic reduction in the productivity of surface water	Large declines in apex predators such as seabirds.

3.6 Overview of direct impacts

Table 3.12 presents a summary of the state of evidence on direct impacts of climate change for priority habitats. It is based on the evidence presented in chapter 6, as interpreted by the authors. It shows that of the 32 habitats, 7 are at high risk of direct impacts, based on good to moderate evidence available, and 5 of these are coastal or marine. It also demonstrates that there is a poor evidence base for 12 habitats.

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Table 3.12 Summary of direct impacts on BAP habitats

Sector	Habitat	Risk of direct impact	Strength of evidence	Comments
Agriculture	Arable field margins	Low	Poor	Strongly influenced by management. Includes species with southerly distributions with expanding climate space.
	Ancient/species-rich hedgerows	Low	Poor	Some hedgerow tree species at risk from drought (e.g. beech)
	Lowland meadows	Medium	Poor	Most at threat from increased water stress. Strongly influenced by management
	Heathland	Medium	Good	Wet heaths most at threat from increased water stress. Also interaction with air pollution/eutrophication. Increased fire risk.
	Montane	High	Moderate	Loss of suitable climate space because of rising temperatures
	Calcareous grassland	Low	Moderate	Fragmentation exacerbated by geological constraints as well as land use. Strongly influenced by management.
	Lowland dry acid grassland	Low	Poor	May increase at expense of heathland.
	Purple moor grass and rush pasture	Medium	Poor	Most at threat from seasonal changes to water table.
Wetlands	Peatland	Medium	Moderate	Summer drought causing drying, tree invasion and peat loss in south and east
	Fen, marsh and swamp	Medium	Poor	Most threats from seasonal changes to water table.
	Standing water	High	Moderate	Disrupted stratification, decline in clear water conditions, increased risk from invasive species
	Rivers	Medium	Moderate	Increased severity/frequency of low flows, reduced suitability for salmonids
Woodland and forestry	Lowland beech and yew woodland	Medium	Good	Beech vulnerable to drought in south and east.

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Sector	Habitat	Risk of direct impact	Strength of evidence	Comments
	Lowland wood-pasture and parkland	Low	Poor	Strongly influenced by management
	Upland mixed ashwoods	Low	Poor	Expected change in tree species composition
	Upland oakwood	Low	Poor	Restricted to oceanic fringe in England
	Wet woodland	Medium Low	Poor	Most at threat from seasonal changes in water table
Towns, cities and development	Terrestrial habitats (parks, gardens, trees, built-up areas))	Medium	Moderate	Strongly influenced by management of site, vegetation and water availability.
	Freshwater habitats	Medium	Moderate	Serious risks of pollution following storm events. Strongly affected by summer drought and changes to water table.
	Inter-tidal and coastal habitats	Low	Moderate	Strongly influenced by management (managed retreat). At risk as a result of sea-level rise, and during storm surge events.
Coastal and marine	Floodplain and grazing marsh	High	Good	Inundation and erosion due to sea-level rise. Changes in flooding regime due to coastal defence works.
	Saltmarsh	High	Good	Inundation and erosion due to sea level rise.
	Estuaries and mudflats	Low	Moderate	Changes in distribution in over-wintering waders and benthic organisms. Reduced organic input due to loss of saltmarsh.
	Sand dunes	Medium	Moderate	Increased erosion due to sea-level rise and more recreational disturbance as a result of warmer temperatures
	Vegetated shingle ridges	Medium	Moderate	Increased erosion due to sea-level rise. Flooding of ground-nesting bird nests

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Sector	Habitat	Risk of direct impact	Strength of evidence	Comments
	Maritime cliffs and slopes	High	Good	Increased erosion due to sea-level rise. Replacement of native species by invasives. Coastal defence works resulting in vegetation changes.
	Rocky shores	Medium	Moderate	Organism distribution shifts. Decrease in brown algae dominated shores.
	Sandy shores and beaches	Medium	Moderate	Increased recreational disturbance due to warmer temperatures. Increased erosion due to sea-level rise.
	Saline lagoons	High	Moderate	Changes in salinity regimes due to sea-level rise induced inundation, coastal defence works, increased winter rainfall and higher summer temperatures.
	Sublittoral rock	Low	Poor	Changes in benthic community. Spread of invasive species such as Pacific Oyster
	Sublittoral sediment	Medium	Poor	Changes in benthic community. Dredging to create coastal defence works.
	Open seas	High	Moderate	Changes in species distribution, increased incidence of stratification, decreased abundance of calcifying organisms

Criteria:

- Impacts
 - High = significant loss of extent/increase in unfavourable condition by 2025
 - Medium = some loss of extent/increase in unfavourable condition by 2025, effects part of range or sub-types
 - Low = predominately influenced by other factors, robust or losses offsets by gains
- Evidence
 - Good = corroborative evidence from a number of sources or methods/high confidence/pertaining to specified habitats
 - Moderate = evidence from one or more sources/range of anticipated outcomes/partial
 - Poor = few relevant studies/contradictory evidence/high uncertainty

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As the climate changes there will be changes socio-economic drivers which in turn lead to changes in the working practices, policies, land use and water resource management within each of the sectors. These changes may have positive or negative implications for biodiversity. This section provides a brief overview of likely changes that may arise in each EBS sector and an assessment of the indirect impacts this may have on biodiversity.

There is great uncertainty surrounding the assessment of the indirect impacts of climate change on biodiversity. There is uncertainty in future changes in socio-economic demands and associated changes in policy, working practices and land and water use. There is the uncertainty associated with the impact that these changes will have on biodiversity. There has been limited research on integrated impacts (Holman and Loveland, 2001; Holman *et al.*, 2005; ACCELERATES, 2004). The assessment given here is largely based upon on basic ecological principles and the knowledge and opinion of the authors.

The discussion of the indirect impacts of climate change on habitats and species in each sector shows that there are both opportunities and threats for biodiversity. An overview summarising these opportunities and threats is given in Section 4.6. Additional information about indirect impacts is presented in Appendix 1.

4.1 Agriculture and farmland habitats and biodiversity

4.1.1 Introduction

The impacts of climate change on agricultural working practices at a global level have been summarized by the Secretariat of the Convention on Biological Diversity (CBD, 2003, CBD, 2006). At a UK level, a report prepared and published by the National Farmers Union (2005) summarizes current thinking about how agriculture will change because of climate change. This section draws heavily on these reports. The topics covered are: food production; biofuels, water management, carbon management, agri-environment schemes and management practices.

4.1.2 Food production

Change in food production due to climate change is likely to be the indirect driver that has the greatest impact on biodiversity in the agricultural sector. Food production may change in three ways:

- type of crop grown,
- area in which any given crop is grown,
- agricultural practice by which the crop is grown.

More flower crops e.g. sunflowers, lupins and borage are likely to be grown and this will benefit species that require nectar sources (Hossell *et al.*, 1996; NFU, 2005). A switch from oil seed rape which is a winter sown crop to flower crops that are spring

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sown (e.g. sunflowers) may increase the area of winter stubble benefiting corn buntings (*Miliaria calandra*), house sparrows (*Passer domesticus*), yellowhammers (*Emberiza citronella*) and other species that rely on this habitat as a food source (NFU, 2005). Linnet (*Carduelis cannabina*) populations are increasingly reliant on oilseed rape for food and are likely to suffer further from this change of crops (NFU, 2005). Vineyards are expected to increase in the south of England, while traditional orchards may decline and be replaced with peach and other fruit crops currently grown further south in Europe (NFU, 2005). Such change is expected to be generally negative for wildlife as the continental European counterparts are intensively managed systems that are poor in wildlife.

The regional pattern of crops is predicted to change with a general increase in the areas that grow barley and an increase in maize production in the north. The increase in maize is predicted to be negative for wildlife as maize crops support few weeds, seeds and invertebrates compared to other crops (NFU, 2005; Burke, 2003; Firbank *et al.*; Hossell *et al.*, 1996; Annell *et al.*, 1999). Cereal production may move away from the south east of England and East Anglia to the west and north. Lowland grass leys may move onto lower yielding arable land and there maybe a decline in sheep production in the lowlands (Parry *et al.*, 1999; Hossell *et al.*, 1996; NFU, 2005). The impact of such regional changes on biodiversity is hard to predict as it is dependent on what the land use was previously and the balance of land use and crop types within a given area.

Warmer springs and longer growing seasons will mean earlier sowing, more autumn planting of winter crops and opportunities for double cropping (NFU, 2005). Harvesting dates may also be earlier. If changes in phenology (flowering time, breeding time) do not keep pace with the changes in the timings of agricultural practices, these changes will be detrimental to biodiversity. Double cropping could mean disturbance during the breeding season and could have a high impact on ground nesting birds such as lapwings (*Vanellus vanellus*) and skylarks (*Alauda arvensis*) (NFU, 2005).

The effects of climate change on livestock and dairy production are extremely complex and variable (NFU, 2005) and it is hard to make generalised predictions about changes in livestock and dairy production caused by climate change. Assuming no limits on fertiliser use, grass growth (the main livestock food) is largely controlled by two factors – temperature and rainfall. There could be complex changes with dry summers in Eastern England making grazing (including that on high biodiversity sites) difficult as a result of reduced grass growth and water available for stock to drink. Conversely, in Northern and Western England if rainfall remains adequate the warmer springs will mean that higher grass productivity will be found in the colder areas.

4.1.3 Biofuels

Policies that promote biofuels and biomass crops have been adopted in several parts of the world including the EU and are promoted under the UK Climate Change Programme (2006). The impact of biofuels on biodiversity depends on the type of biofuel grown and the land use it is replacing (Secretariat of the Convention on Biological Diversity 2003; Hossell *et al.*, 2006). In intensive arable areas or on

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degraded land, willow coppice grown as a biofuel may provide some biodiversity benefits, especially if native species/hybrids are planted (Hossell *et al.*, 2006). In contrast, short rotation coppice planted on semi-natural habitats would damage existing biodiversity. The location and scale of such schemes could also have effects. Large areas of monoculture could reduce habitat mosaics and present barriers to dispersal, especially if they are cropped simultaneously. Small areas located to enhance woodland corridors or extend woodland edge habitat could increase the habitat mosaic and enhance biodiversity. The cropping regime may also impose severe disturbance and removal of habitat that may have been colonised or used by wildlife for dispersal, shelter, breeding or foraging. The non-native elephant grass (*Miscanthus*) is becoming a common biofuel but has little proven benefit for biodiversity. It is likely that there will be a requirement for nitrogen and phosphorous addition to land and a requirement for applications of herbicide and pesticides to enable successful growth of the biofuel crop and this will be detrimental to biodiversity and may impact on water quality.

4.1.4 Water management

As the climate warms there is initially likely to be an increase in demand for irrigation; this may cause low flow in rivers, over abstraction of other surface waters, lowering of water tables, leading to degradation of water resources and aquatic ecosystems with general negative effects on biodiversity (Secretariat of the Convention on Biological Diversity, 2003, 2006; NFU, 2005; Holman and Loveland, 2001; Holman *et al.*, 2005). As water scarcity increasingly becomes an issue this is likely to cause increased regulation and a decrease in irrigation of agricultural land. There may be an increase in development of water storage facilities, or reservoirs to supply water for irrigation, which could lead to losses of semi-natural habitats in less productive areas of individual farms. There may also be increased attention to ditch management, which could be beneficial or detrimental to wildlife, depending on whether the method and timing of management included consideration of biodiversity interests. Other aspects of water management are included in Section 4.2.

4.1.5 Carbon management

Climate change mitigation policy aims to minimise releases of carbon dioxide and other greenhouse gases to the atmosphere and encourage methods to sequester carbon. In the agricultural sector such methods may include increased forestry (see Section 4.3), conservation tillage methods, erosion control practices, improved management of grassland to enhance carbon storage and the maintenance of peatland and mires as carbon stores (Secretariat of the Convention on Biological Diversity, 2003, 2006; UK Climate Change Programme 2006).

Conservation tillage includes methods such as chisel-plough, ridge-till, strip-till, mulch till and no-till, all of which allow for the accumulation of soil organic carbon (Secretariat of the Convention on Biological Diversity, 2003, 2006). The impact of these methods on biodiversity depends on the practice and context in which they are applied. They may provide beneficial conditions for soil fauna and thus be of benefit to biodiversity, but may be detrimental to biodiversity if low tillage leads to increased herbicide application (Secretariat of the Convention on Biological Diversity, 2003, 2006). Erosion control practices include such measures as water conservation

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structures, vegetated strips and agroforestry shelterbelts, all of which reduce the release of soil organic carbon (Secretariat of the Convention on Biological Diversity, 2003). These methods may have some positive benefits for biodiversity but it depends on which practices are used. Improved management of grassland to enhance carbon storage can be beneficial for biodiversity if native species are used, but if introduced species are used to fix nitrogen there may be a risk of these species becoming invasive weeds

4.1.6 *Agri-environment schemes*

Environmental Stewardship (ES) is a scheme which provides funding to farmers and other land managers in England who deliver environmental management on their land (<http://www.defra.gov.uk/erdp/schemes/es/default.htm>). It was launched in 2005 to replace the Countryside Stewardship and Environmentally Sensitive Area agri-environment schemes. Its primary objectives are to

- Conserve wildlife (biodiversity)
- Maintain and enhance landscape quality and character
- Protect the historic environment and natural resources
- Promote public access and understanding of the countryside
- Natural resource protection

Within the primary objectives it also has the secondary objectives of:

- Genetic conservation
- Flood management

ES consists of three strands Entry Level Stewardship (ELS), Organic Entry Level Stewardship (OELS) and Higher Level Stewardship (HLS). ELS and OELS are open to all farmers in England, while HLS is competitive, paying for significant environmental benefits in high priority areas or situations.

Addressing climate change is not currently an objective of the scheme but it is likely to be included in the 2007 review of ES. Agri-environment schemes encourage less intensive agriculture, which may mitigate climate change. Changes in agri-environment schemes towards the promotion of ecological networks and the conservation of ecosystem services are generally intended to benefit biodiversity. Nevertheless a change in policy emphasis towards ecosystem services with increased focus on human requirements may mean reduced emphasis on protection of rare and endangered species and their habitats (Secretariat of the Convention on Biological Diversity, 2003). Whilst the target area for ES (60% of England's agricultural land by December 2007) seems substantial, it should be noted that only a proportion of this land will be managed using options that are designed to reduce inputs. Defra has commissioned research to estimate the extent that agri-environment schemes contribute to climate change mitigation (report due 2007). Early indications are that, although there are some options that could deliver significant increases in carbon sequestration (compared with conventional agriculture), they tend to be those options with the highest cost.

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4.1.7 Management practices

Changes in land use and management in response to climate change may include drainage to avoid increased risk of flooding, and changes in livestock farming practices. Increased drainage will be detrimental to biodiversity (NFU, 2005). Warmer temperatures may mean that animals would not necessarily need to be removed from higher ground during the winter and there may be opportunities to finish cows and sheep in upland areas. This will benefit biodiversity if it reduces grazing on overgrazed land but if it increases the grazing intensity on *Calluna* moorland it will lead to a loss of *Calluna* and an increase in grass species and generally be detrimental to biodiversity (NFU, 2005; Secretariat of the Convention on Biological Diversity, 2003).

Livestock farming may decline in the south and east of England if summers become hotter and drier. The likelihood of this change in livestock husbandry happening depends on factors such as the length of growing season, rainfall and soil type and economics (NFU, 2005). Little is known about the impact such a shift in livestock production would have on biodiversity, but grazing pressure is an important aspect of management of many semi natural habitats, which have developed as a result of traditional livestock management practices. Grazing checks the growth of rank vegetation and prevents a small number of fast growing species competitive species from excluding others. It may also provide the microclimate required by sensitive species at the edge of their climatic range.

Climate change may drive changes in fertiliser and pesticide use and changes in the timing of agricultural practices. For example, milder winters may allow more pest species to survive resulting in an increase in pesticide usage. This will be detrimental to biodiversity; for example, corn buntings (*Miliaria calandra*) and grey partridge (*Perdix perdix*) have been shown to struggle to feed chicks from a reduced food source where pesticide applications are high (Pearce, 2001).

Regulated dates for burning of heather moorland and of cutting meadows may have to change as the breeding season for birds begins earlier with climate change. In addition, with an increase in the number of hot dry summers, there may be an increase in the number of accidental and uncontrolled summer fires, particularly on heathlands, which is likely to be detrimental for biodiversity (Rose *et al.*, 2000).

4.1.8 Coastal change

Major changes in land-use are likely to occur on coastal grazing marshes as a result of sea level rise. As inundation of these areas increases, they are likely to become less favourable for maintaining livestock. Often the conservation value of such habitats is enhanced by short sward lengths and the presence of pools of freshwater maintained by livestock grazing and trampling (Hart *et al.*, 2002; Norris *et al.*, 1997; Tichit, Durant and Kerneis, 2005). Reductions in grazing in response to sea-level rise may have detrimental consequences for biodiversity in this habitat.

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4.1.9 *Wind farms*

Development of wind farms at the site level may have significant impacts through disturbance, changes to drainage, habitat fragmentation and bird strike (Stewart *et al.*, 2004, Hossell, 2006). These impacts may be mitigated by careful design and compensatory mitigation measures. In the longer term, at a global scale, reduced CO₂ emissions contribute to the mitigation of climate change and may therefore reduce its impacts on biodiversity.

4.1.10 *Summary: agriculture*

Agriculture responds rapidly to changes of policy, market forces and innovations in management and technology. There are both benefits and threats to biodiversity from indirect impacts of climate change associated with agriculture which affects approximately 72% of England's land surface area (Agricultural Census data for 2005). Changes in the types of crops grown and geographical shifts in regions where different crops could be grown may benefit biodiversity provided that they increase habitat heterogeneity, contribute to habitat networks and provide suitable habitat for foraging, shelter, breeding or dispersal. Achieving positive benefits for biodiversity may also require sympathetic timing or methods of operation, such as timing harvest to avoid effects on breeding birds or harvesting different areas at different times on a rotation. The increase in biofuels could potentially affect large areas, and offers many potential benefits and threats, depending on sympathetic design and other needs.

Carbon management schemes may increase soil biodiversity through tillage and erosion control techniques, which could also benefit biodiversity through effects on food webs and increasing habitat heterogeneity, depending on methods employed.

Changes in land use, intensity and distribution of farming systems and environmental management may have a far greater effect on biodiversity than introduction of novel crops. Management practices may change, and the change in land use could potentially have large widespread impacts on biodiversity. For example, there may be changes in upland grazing regimes or reduction in grazing in southern areas. Increased frequency of arable weed opportunist species and over winter survival of pest species may also result in increased application of herbicides and pesticides with potential adverse impacts on other species and the aquatic environment.

There is a high level of uncertainty in anticipating future changes in policy, management practices and farmer's choice of options in response to climate change. This gives rise to further uncertainty in predicting the indirect impacts of these changes and interactions of climate change on biodiversity. Given the dependency of farmland biodiversity on agricultural land management, these indirect impacts could be substantial and result in more significant impacts on biodiversity than the direct impacts of climate change.

See Table 4.1 for a summary of the opportunities and threats to biodiversity across all sectors under climate change.

4.2 Water and wetland habitats and biodiversity

4.2.1 Introduction

Climate change in the UK is likely to result in altered seasonality of precipitation and changes in the absolute amount of precipitation. Indirect impacts of climate change upon water and wetland habitats will be primarily mediated through altered water resource management. There is uncertainty about the impacts of climate change on water and wetlands, which is closely linked to regional variation in the predicted availability of water under different climate change scenarios. The topics covered here are: flood defence, conservation, freshwater fisheries, navigation, energy and carbon.

4.2.2 Flood management

Considerable effort is already devoted to dealing with predicted higher water levels and hence greater flood-risk, both within the coastal/estuarine zone and freshwater systems (Ramsbottom *et al.*, 2005). Changes in flood defence that are already under way concentrate on confining excess waters within “safe” bounds. In river floodplains, actions include raising of flood-banks, greater demand for flood-storage and upgraded controls through barrages and sluices. Higher flood-banks ensure greater capacity within the channels and more control over flooding, not only of the agriculture, industry and housing, but also of floodplain wetlands. Unless engineering of the banks includes systems of slackers and more subtle regulation, then the probable impact of raised banks will be to further divorce the river from its floodplain, reducing water inputs to wetlands and opportunities for dispersal of animals and plant propagules by water. Flood storage within existing drainage channel networks, floodplains or within new wetland restoration schemes is proposed as a remedy to accommodate the increased rainfall expected, particularly in winter. Such plans interact with management for biodiversity:

- Negatively - where raised ditch water-levels are used as a prescription to rehabilitate wetlands (particularly wet grasslands); such action may reduce flood storage capacity (Acreman *et al.* in press).
- Positively - where extant large wetlands are drying out or where wetland creation schemes are proposed; such sites may be used to accommodate flood waters and to provide flexible management of excess water (Mountford *et al.*, 2002). There are caveats to this type of integrated management, notably where flood waters are nutrient-rich and incompatible with conservation of certain types of wetland.

Policies which designate and protect floodplains and washlands can increase the areas available as potential wildlife habitat (e.g. OST, 2004; Environment Agency, 2005; ABI, 2004, 2005; IPPR, 2005).

Barrages (flood barriers) and sluices are advocated to mitigate tidal or flood surges. Like flood-banks, such increased engineering controls may provide scope for targeted management that allows wetlands to coexist with intensively-used land, but such a flexible approach requires thorough planning and supervision. Any barrier across a natural river can have impacts both on the movements of migratory fish

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species and the river's function in seed dispersal. , Design and engineering of effective bypasses around barriers can be effective where biodiversity considerations are paramount (Haskoning, 2006).

Managed realignment is an important coastal policy responding to climate change (Cobbold and Santema, 2001; Hampshire County Council, 2003; RSPB, 2001; National Trust, 2005). Planning for managed realignment can include compensation for lost habitats in newly flooded areas. Some freshwater and brackish wetlands of international importance are threatened by sea-level rise and managed retreat, whereby low-lying coastal areas are allowed to be flooded.

4.2.3 *Water availability and catchment management*

Decreasing summer rainfall and increasing demand for water, especially in the south and east of England, will reduce water supplies with implications for the feasibility of wetland restoration and management schemes. For example, it may no longer be possible to maintain appropriate hydrological regimes for the protection of biodiversity in many of the small, scattered, discrete nature reserves and large-scale wetland restoration schemes (Mountford *et al.*, 2004), which are also increasingly a feature of lowland England, especially within the Fens.

Wetlands with international designation (e.g. Ramsar and Natura 2000 sites, SACs and SPAs) have a legal requirement for government agencies to maintain water supply, whereas those with lower or no level of protection may be liable to deterioration through neglect. In those parts of the landscape outside of protected areas or restoration schemes, competition for water resources between agriculture, industry, housing and biodiversity is likely to intensify. This is likely to lead to the loss of scattered wetland fragments, which currently support local biodiversity in the wider countryside and which may be important as sanctuaries for survival or as stepping stones for dispersal of some species.

The EU Water Framework Directive (2000/60/EC) makes demands from government, its agencies and the private sector on the management of water resources and specifically on the achievement of high ecological status in surface waters. As with the Natura 2000 network, policy derived from the WFD will make stringent demands that should provide a pressure for effective conservation in freshwaters and wetlands under a changing climate.

4.2.4 *Energy generation*

Changes in energy policy to meet reduced carbon emission targets could affect both waters and wetlands. Renewable means of energy generation include hydroelectricity, both large-scale on main rivers and as micro-hydro plants on tributary streams. Both developments are designed to reduce CO₂ emission, and in the medium to long term may benefit biodiversity. In the shorter term the impact of such developments may be more negative on local biodiversity. For example development of micro-hydro plants as a widespread means of local power generation could include placing barriers over many headwater streams that are presently essentially natural. This would disrupt fish migration and movement of propagules

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and may cause damage to channel morphology and habitat availability through scouring and erosion of the stream bed downstream.

4.2.5 *Carbon management*

As discussed in section 4.1.5, changes in carbon policy advocate measures to reduce emissions and promote carbon sequestration. Peatland, mires and bogs act as sinks (stores) of carbon. Promotion of measures to avoid degradation of these systems to preserve the carbon stored may also benefit biodiversity by promoting the conditions, which reduce erosion of the peat, favour characteristic species of mires and bogs and which may lead to active accumulation of peat. (Secretariat of the Convention on Biological Diversity, 2003; Defra, 2006c). Maintenance of wet peatlands within agricultural landscapes is a goal of agri-environment schemes, justified in terms both of inherent biodiversity and reduction of emissions. Schemes promoting raised water levels in peatlands, mires and bogs are expected to have this benefit, although recent research indicates that current prescriptions are insufficient to completely prevent continued carbon loss (Lloyd, 2006). Drying and erosion of peat and associated carbon release can be reduced by wetting the peatlands, though this may be offset in part by increased emission of methane. If successful, the large-scale wetland restoration schemes of Fenland will create wetland conditions over at least 10,000 ha, as well as preserving the peat in the relict fen NNRs. There is potential in such schemes to re-start peat accumulation, with consequent sequestration of carbon (www.europeat.alterra.nl/).

4.2.6 *Tourism and recreation*

Tourism and recreation in the UK is expected to increase because of climate change and public attitudes towards air travel. This could lead to increased visitor pressure on water bodies, rivers and wetland habitats of high biodiversity value such as the Norfolk Broads and Lake District lakes.

4.2.7 *Summary: water and wetlands*

Indirect impacts of climate change on water and wetlands are mainly associated with changes in the hydrological regimes with increased need for management of flood, drought and managed retreat, but each offers opportunities and poses threats to biodiversity. Flood management may offer some benefits for biodiversity by habitat creation and floodplain management, but some existing habitats may be replaced. Flood barriers may be engineered to mitigate adverse impacts on migrating or dispersing river species but will inevitably impose some impacts on local river habitat. Managed re-alignment may offer opportunities for biodiversity and provide compensation for lost habitat, but there will be inevitable overall losses of habitat quantity as sea level rises. There may be problems associated with drought and increased demand for water (especially in the south east) with competition for water from agriculture, industry, home use and potable supplies. While supplies to internationally protected sites are relatively secure, supplies to other scattered designated sites with wetland habitats or non designated wetland habitats (including ponds and wet ditches) may not be sustained resulting in losses of species, dispersal routes and habitat types.

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The importance of wet peatlands in sequestering carbon is increasingly recognised and schemes to promote this habitat function will benefit biodiversity.

There may be increased visitor pressure on wetland, lakes and river habitats with impacts on water quality and species supported and impacts on the wetland habitat and species due to disturbance (noise, waves etc).

See Table 4.1 for a summary of the indirect impacts of climate change across all sectors.

4.3 Woodland and forestry habitats and biodiversity

4.3.1 Introduction

Policies for woodland and forestry in England are varied and are likely to change significantly in response to climate change. Policy development will need to take account of potential timber production, the sequestration of carbon, optimising water management and providing leisure opportunities, as well as the conservation of biodiversity. Changes in policy for other sectors, particularly agriculture, also impact on woodlands and forestry.

4.3.2 Timber production, carbon management and biofuels

Short term market conditions are relatively less important for forestry than agriculture, but patterns of global trade in forest products do nevertheless strongly influence the nature of English forestry. At present most forest products are imported into the UK and in recent decades, there has not been a strong financial or strategic incentive to maximise timber production. This context has allowed biodiversity conservation to become a relatively high priority for forest management for many land owners, especially in the public sector. This situation may change if pressure to maximise production of timber from UK sources increased. Scandinavia and the Baltic States are the main sources of timber imports at present and are likely to maintain forest productivity under climate change. It is possible that increasing demand and declining productivity in other areas may stimulate demand and push up prices, which might in turn make timber production in the UK more financially attractive and strategically desirable. Tree growth in the north and west of England is likely to increase with warmer temperatures (unlike in the South East where drought may offset this). Increased productivity could make forestry more profitable than in recent years.

Specific climate change, energy and carbon sequestration policies encourage timber production. An increase in the use of biomass, for example, for use in local heating schemes and co-firing power stations has recently been supported by the government in their response (Anon. 2006) to the Biomass Task Force (2005). In the short-to-medium term, a potential way forward in reconciling the needs of biodiversity and conventional forestry is by encouraging the planting of mixed species and mixed provenance stands in order to keep options open. As the effects of climate change on plantations become manifest in maturing crops there may be economic considerations favouring elimination of less productive species when thinning, even if they are of high biodiversity value.

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The creation of new woodland on agricultural land is a likely outcome of mitigation strategies to sequester carbon dioxide and to generate renewable energy, either because of direct incentives to plant trees or a change in market conditions. This is consistent with the England Biodiversity Strategy, but the nature and location of these new woodlands will have major impact on their value for conserving and enhancing biodiversity (Hardcastle, 2006; Secretariat of the Convention on Biological Diversity, 2003). Creation of new woodland can increase or decrease biodiversity, depending on the habitat that it replaces.

If an area of intensively managed agricultural land becomes woodland, there would typically be an increase in the abundance and diversity of plant and animal species supported. Adverse impacts on national biodiversity would result if semi-natural habitats, such as heathland, were to be converted to woodland.

The nature of the woodland and its management regime is also a key factor in assessing the implications for biodiversity. Some forms of tree production, in particular short-rotation coppice (SRC), which has very short rotations (3 years or less) and high agrochemical inputs, support very few species (Secretariat of the Convention on Biological Diversity, 2003). It may be possible to develop these systems in ways that could provide some benefits for biodiversity (Hossell *et al.*, 2006), such as contributing to regional or local habitat networks, increasing the local habitat mosaic, extending woodland or woodland edge habitat, and adjusting the timing and sequence of cropping rotations to avoid impacts on local species. Short rotation forestry (SRF), which has longer rotations (8-20 years) than SRC has been recently reviewed by Hardcastle *et al.*, (2006) who concludes that 'although SRF will usually increase biodiversity compared with cropland, pasture or SRC, those taxa that require mature trees and/or dead wood will not benefit from SRF.'

The species planted will also make a difference to biodiversity interests. Planting of fast growing, non-native species, including *Eucalyptus* species, has been proposed, which would be expected to support a lower invertebrate biodiversity (Hardcastle *et al.*, 2006) than native tree species, although there is little direct evidence to date.

If there is an increased market for timber and other wood products, there would almost certainly be an increase in the extent of management intervention in existing woodlands. The government has already asked the Forestry Commission to 'identify the measures needed to deliver progressively an additional 2 million tonnes per annum (0.4 Mt carbon saved) from existing woodlands, with a focus on currently under-managed woodland' (Response to Biomass Task Force, Anon., 2005).

The consequences for woodland biodiversity are mixed and would depend on the nature of the management operations. The most productive woodland has typically been one in which timber extraction has been maximised, trees have not been allowed to become 'over-mature' and there has been little dead wood. However, old, 'veteran' trees and deadwood provide habitat for specialist species, many of which are rare. Deadwood species would be adversely affected by higher rates of timber removal. On the other hand more frequent opening of the canopy, through thinning, would favour many plant species of the forest ground layer and the animals they support. Clear-felling and major disruption of the soil surface would be damaging for

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most types of organisms either directly because of the physical damage or the changed microclimate.

Wetter winters may cause water-logging in areas which have not previously experienced serious problems. This may lead to timber extraction work being carried out at other times of year which may in turn have implications for wildlife and ground flora, especially given the lengthening of the growing season and earlier breeding seasons brought on by climate change. Increases in serious pests and pathogens caused by climate change could lead to greater attempts at control which may have undesirable side effects on non-target species (Broadmeadow and Ray, 2005; Broadmeadow, 2000; Broadmeadow, 2004; Broadmeadow, 2002).

There are moves towards silvicultural techniques which more closely follow natural patterns. These include Continuous Cover Forestry, where a tree canopy is maintained by selectively felling individual trees or small groups at any one time; the use of natural regeneration and allowing some accumulation of dead wood. Such approaches are widely used in some other parts of Europe and they may offer the best way of reconciling the needs of biodiversity conservation, timber production and carbon sequestration.

4.3.3 *Water Management*

Water management is expected to become more important under climate change, both from the point of view of improving supply during times of drought and reducing the impact of flooding. One positive outcome for conservation may be encouragement to protect wet woodlands and plant new ones in areas that are prone to flooding (Broadmeadow, 2002). Wetland plants are specialised to tolerate the water environment and can contribute to improved water quality. They help trap sediments and many can take up pollutants such as metals. Wetland trees such as alder often have root – bacterial associations which increase uptake of nitrogen, contributing to removal of pollutants from water. Their roots also help stabilise soils, increasing resistance to erosion during peak flows. Shading offered in summer months may also help combat effects of increased water temperatures, offering sanctuary areas where temperature sensitive aquatic species may be able to survive. Trees planted in catchments increase interception of rain water, delaying percolation through the soil and reducing peak flows and soil erosion.

There is a converse argument that because forests generally use more water than other land uses and there may be pressure not to plant trees in drought sensitive catchments. Deciduous species may be favoured in planting schemes as they tend to have lower water losses than evergreen species.

4.3.4 *Recreation and Tourism*

An increase in the use of forests for leisure activities has been seen in recent decades and this may increase again if warmer, drier summers make holidays in the British Isles more popular. This may encourage the planting of woodland and management for wildlife to increase the attractiveness of areas to visitors. The effects of visitor pressure on biodiversity may be adverse where there is, for

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example, increased trampling of ground flora, dumping of rubbish, creation of car parks or visitor centres and disturbance.

4.3.5 *Summary: woodland and forestry*

Currently, most timber is imported to the UK, allowing biodiversity conservation to be a relatively high priority for forest management, but this situation could change if pressure to maximise production of timber from the UK increases. Tree growth in the north and west of England is likely to increase, which may make forestry more profitable than in recent years. The importance of woodlands in sequestering carbon is increasingly recognised and schemes to promote this habitat function will benefit biodiversity. The impact on biodiversity of new woodlands for carbon sequestration or biofuel production will depend on the species of trees planted, the management of the woodland and the location of the woodlands. Short rotation forestry is likely to be more beneficial to biodiversity than short rotation coppice, cropland, or pasture, however, those taxa that require mature trees or dead wood will not benefit. A move towards continuous cover forestry with natural regeneration and tolerance dead wood may offer the best way of reconciling the needs of biodiversity conservation, timber production and carbon sequestration.

Increasing the area within a catchment planted with trees will increase interception of rainwater, delay percolation through the soil and reduce floods and soil erosion with benefits for adjoining and aquatic habitats. An increase in the area of wet woodland would be beneficial to biodiversity. However, in drought sensitive catchments, there may be pressure not to plant trees as forests generally use more water than other land uses.

An increase in the use of forests and woodlands for recreational purposes may result in increased disturbance and trampling which may be locally detrimental to biodiversity but may encourage the planting and management of woodlands for wildlife.

4.4 **Towns, cities and development**

4.4.1 *Introduction*

Changes in several policy areas as a result of climate change are expected to lead to impacts for biodiversity which may be positive or negative. The policies considered here are urban planning and building design, water resources, energy and waste management.

4.4.2 *Urban planning and building design*

Certain working practices of planners and managers of urban areas and development are being influenced by climate change, with potential impacts for biodiversity. These include the practice of Strategic Environmental Assessment (SEA), Sustainability Assessment (Treweek and Therivel, 2005) and Appropriate Assessments (Scott Wilson *et al.*, 2006), which may be modified to raise the profile of green spaces and functional ecosystems within urban areas and give priority to their creation and maintenance. Similarly where planning gain obligations (measures

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required to mitigate the impact of new developments) are incurred, benefits provided may focus on provision of potential habitat areas rather than other benefits.

The proportion of existing building stock greatly outweighs the annual new-build (99:1), so there is little opportunity for radical and rapid re-design of urban settlements. Acting over the long term, changes resulting from perceptions of climate change and from climate change related events are leading to changes in building and settlement policy. The Code for Sustainable Homes (ODPM, 2005b) is intended to bring in voluntary compliance on aspects including energy efficiency and surface water management (see below) as well as use of materials. All these may have consequences for biodiversity.

In urban areas, climate change is leading to a review of policies promoting use of brownfields and compact, dense development, in order to maintain or increase the cooling and rainfall attenuation functions of green spaces (Mayor of London, 2005). Incorporating more parks and gardens in urban areas provides opportunities for wildlife and its dispersal. Intensification of settlement offers potential to reduce travel and consequently, emissions (ODPM, 2005a, Gwilliam, 1999), but more densely built towns and cities are associated with habitat fragmentation and loss of habitats within urban areas (Thompson, Austin *et al.*, 2003) and loss of permeable surfaces (Greater London Authority, 2005). Beneficial effects for biodiversity could result from the introduction of more trees to provide shade for buildings and open spaces, or the use of green walls and roofs to reduce solar gain, though these effects act on a small scale.

Sustainable drainage systems (SuDS) that may be introduced as a response to flood risk under climate change also offer significant opportunities at the local level for biodiversity protection and enhancement (ODPM PPG 25, 2001; Environment Agency, 2003; ODPM, 2005b).

Climate change impacts will also have consequences for other urban management practices. The management of parks and gardens will change: introducing new drought tolerant species and varieties will have potential impacts for associated species. Any changes in the timing of operations and pest management in parks and gardens will also affect urban biodiversity, including invertebrates and their predators and seed set by wild plants.

4.4.3 Water resources

Policies relating to water resources and development are very closely linked, and water supply and efficiency policy is changing as a result of climate change (see also Section 4.2). Where development leads to greater use of water resources this may present a threat for wildlife habitats, such as the permission to increase or maintain abstraction licences in times of drought (Downing *et al.*, 2003). On the other hand, provision of new resources over the longer term can lead to conflicting impacts: new water resources can provide opportunities for new habitats or other wildlife resources such as networks and patches. Inappropriate development will threaten habitats, for example, where a reservoir is inappropriately designed and located. Cross-basin water transfer will change the nature of local water and flows, with consequences for aquatic and wetland biodiversity (Environment Agency, 2005).

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More efficient use of water could reduce pressure on resources, thereby safeguarding water supplies to aquatic and wetland habitats, so long as they do not merely serve to offset new demand (IPPR, 2005).

4.4.4 *Energy and waste management*

Energy policy is changing in the light of climate change, with the recognition of the need to improve efficiency, increase the use renewable sources and reduce emissions. In the urban sector, energy generation via solar panels and wind turbines is expected to have less potential impacts on biodiversity than wind turbines built in the semi-natural habitats covered under the agricultural, and coasts and seas sectors (Section 4.1 and 4.4). Promotion of urban cooling can save energy from running air conditioning, and can be promoted by shading, water features and building design may lead to increased opportunities for wildlife habitats (London Assembly, 2005; Hacker *et al.*, 2005; EPSRC and UKCIP, 2005

Waste management will also need to adapt to climate change (Bebb and Kersey, 2003) but the potential impacts of these changes on urban biodiversity have not been identified. Restored landfill sites have shown some value for nature conservation (Watson and Hack, 2000).

4.4.5 *Summary: Towns, cities and development*

Codes of practice for planners and managers in urban areas are changing as a response to climate change, e.g. SEA, sustainability assessment, SUDS and Appropriate Assessments with potential impacts for biodiversity. Promotion of urban cooling via shading, water features and building design may lead to increased opportunities for wildlife habitats. New drought-tolerant species and varieties will be introduced to parks and gardens with potential impacts for associated species. Any changes in the timing of operations and pest management in parks and gardens will also affect urban biodiversity.

See Table 4.1 for a summary of the indirect impacts of climate change across all sectors.

4.5 **Coasts and seas habitats and biodiversity**

4.5.1 *Introduction*

There are a number of policy areas for the coast and seas which may be affected by climate change. The main ones are policy relating to fisheries, flood control and sea defences, tourism and coastal development and renewable energy.

4.5.2 *Fisheries*

In the open seas, the policy most likely to have implications for the extent to which biodiversity can accommodate changing climate is fisheries policy, particularly the setting of fisheries quotas. Whilst not a climate-related policy in itself, any modification of existing fisheries policy to account for the effects of climate change is

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likely to have a major impact on fish, but also other biodiversity associated with the open seas (Pitcher, 2005).

The major implications of climate change on fisheries has been recognised for many years (Cushing, 1982; Southward, Boalch and Maddock, 1988; Alheit and Hagen, 1997). In 1992, the International Council for the Exploration of the Seas (ICES) established the Cod and Climate Change program (CCC) to look at climate change effects on cod stocks and also to apply the information to estimate effects on other less well studied species (Ottersen, Drinkwater and Brander, 2004). There have been occasional discussions on how fisheries policy should adapt to take into account evidence on climate change and fisheries (Healey, 1990), but fisheries managers and policy makers have generally been slow to consider its implications (Clark, 2006). For UK fisheries, for which policy is developed at the European level, much of the recent focus has been on moving from single-species management to an ecosystem based approach (Frid, Paramor and Scott, 2005). An ecosystem based approach will require more scientific data than is traditionally used for fisheries management (Frid, Paramor and Scott, 2005, Frost and Hawkins, 2006). If policy makers adopt a more precautionary approach when assessing sustainability of fish stocks in the light of climate change, then some of the effects of climate change could be ameliorated by reducing fishing pressure in order to compensate. This could be very important for heavily fished areas such as the North Sea where there is a rapidly growing amount of evidence on the direct and indirect effects of climate on fish (Perry *et al.*, 2005; Beaugrand *et al.*, 2003). Much depends on the success of the reformed Common Fisheries Policy (http://ec.europa.eu/fisheries/cfp/2002_reform_en.htm) which aims not only to use a full ecosystem based approach to fisheries but also to take into account long-term change in order to set long-term objectives for maintaining stocks. If policy makers do not address the issues of the type of data required for this approach and fisheries quotas continue to be set using inadequate information, already threatened fish will become further threatened (Kelly and Codling, 2006).

4.5.3 Flood control and sea defences

In coastal areas flood risk management policy could have an important impact on the extent to which biodiversity can accommodate climate change. The impacts of sea-level rise will be minimal if sea level rise is viewed as an inevitable process and coastal areas are re-aligned through management such that there is no overall loss of important habitats (Crooks, 2004; Hughes, 2004). Should coastal defence works be placed around much of the coast, many areas of important habitat will be lost as they are squeezed between rising seas and hard defences (Rehfishch and Austin, In press; Rehfishch *et al.*, 2005). Coastal defence works may nevertheless provide opportunities for rocky shore species (Moschella *et al.*, 2005).

Two of the most important coastal habitats in England are saline (and brackish) lagoons and areas of coastal grazing marsh containing pools of freshwater used by breeding and feeding waders (Maclean *et al.*, 2005; UKBAP, 2005). Animals and plants associated with these habitats can only tolerate a finite range of salinity or flooding conditions (Boorman, 1992; Olf, Bakker and Fresco, 1988). With the presence of appropriately designed flood defence works, water-level and salinity regimes could be controlled to enhance biodiversity.

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Tidal barrages may also increasingly be used to for flood prevention (and energy renewal – see 4.5.5).

4.5.4 *Tourism and coastal development*

A recent report has stated that climate change will enhance pressure due to tourism through increased visitor numbers to the coastal zone, a longer tourism season, increased tourism infrastructure (i.e. hotels, attractions, marinas), increased waste (i.e. sewage, solid waste) and increased environmental destruction (Viner, 2006).

The anticipated increase in visitor pressure to many coastal areas in response to warmer temperatures will afford both opportunities and threats to biodiversity (Coombes *et al.*, 2005). Areas of high biodiversity such as England's marine wildlife reserves have been shown to be vulnerable to increased numbers of visitors (Pinn and Rodgers, 2005) and studies in England and elsewhere have shown that increased visitor pressure can adversely affect both sediment (Chandrasekara and Frid, 1996; Brown and McLachlan, 2002) and rocky shores (Fletcher and Frid, 1996; Brown and Taylor, 1999; Keough and Quinn, 1998). Bird species such as ringed plover will also be adversely affected due to increased disturbance (Liley, 1999). The adverse effects on biodiversity will have to be weighed against potential benefits such as an increased educational awareness and improved perceptions and attitudes to coastal environments (Thompson, Crowe and Hawkins, 2002; Brown and McLachlan, 2002). All these factors are likely to be exacerbated by longer tourism seasons due to longer summers and the fact that areas such as southwest England are already seeing increased visitor numbers as more people holiday in the UK to take advantage of good weather (http://www.swenvo.org.uk/environment/climate_change.asp).

In addition to the extra infrastructure required for an increase in tourism, residential developments may also increase due to the enhanced value placed on living in coastal areas. This is expected to increase for certain areas in the light of climate change. Research into the nature of the interactions that exist between climate change, the marine environment and tourism is still in its early stages and further investigation will be required for policy makers to be able to make informed decisions (Viner, 2006).

4.5.5 *Renewable energy*

One of the anticipated indirect impacts of climate change on biodiversity of the coasts and seas sector is the construction of tidal barrages and the development of offshore windfarms. The driving force behind the construction of tidal barrages is the opportunities for generating renewable energy but it is also a consequence of the need to provide flood protection for the increasing numbers of people living in coastal low-lying areas and the increased risk of flooding. Policy is developing so that tidal barrages and windfarms may increase in number in the future with the expectancy that by 2020 3% of the UK electricity supply could come from wave and tidal stream energy (Hay, 2006).

There has been more attention paid to the impacts of windfarms in the north Atlantic region than to tidal barrages, mainly focused on the potential impacts on birds

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(Garthe and Hüppop, 2006; Exo, Hüppop and Garthe, 2003). There is also evidence from studies from Sweden that windfarms can affect demersal fish (those that live primarily near the seabed) by acting as aggregation devices (Wilhelmsson, Malm and O'hman, 2006). Also, there is concern regarding the potential effect of noise and vibration from windfarms on marine mammals, some fish and other species sensitive to noise affects (Vella *et al.*, 2001).

Tidal barrages are less well studied but there is evidence of potentially adverse impacts on biodiversity, particularly on birds (Clark, 2006). Windfarms and tidal barrages affect biodiversity by providing habitat for species associated with natural hard substrate (Hiscock, Tyler-Walters and Jones, 2002). This could have positive impacts in increasing biodiversity at a local level or negative impacts due to the potential for structures to facilitate the introduction and spread of non-native species (Hiscock, Tyler-Walters and Jones, 2002).

The most comprehensive review concerning the potential ecological effects of Offshore Renewable Energy Developments (OREDs) has been carried out by Gill (Gill, 2005). This review suggested three phases over the life of an ORED where disturbance would occur, 1) construction, 2) routine operation and 3) decommissioning (Gill, 2005). Evidence for both direct (construction effects on benthic diversity, impacts of noise and electromagnetic fields, problems with collisions or avoidance behaviour in species) and indirect impacts (impacts on food availability, competition, predation and reproduction and recruitment) was reviewed with the conclusion that OREDs will have impacts on marine ecology at a range of spatial scales. It was, therefore, considered important for ecologists be more involved in the process of ORED if adverse effects on marine biodiversity and ecosystems are to be avoided (Gill, 2005).

As the government is committed to having 20% of its energy come from renewable resources by 2020 (DTI, 2003), there is an increased potential for impacts on biodiversity. Impacts can be minimised, if comprehensive Environmental Impact Assessments (EIAs) are carried out according to government guidelines (Defra, 2005c) along with appropriate monitoring. Despite rapid growth in research relating to renewable energy, there has been little addressing the potential ecological impacts, which is necessary to make informed decisions (Gill, 2005).

One human adaptation to climate change would be for a gradual migration away from areas at risk of flooding, thereby reducing the need for tidal barrages. In contrast, people could also increase the number tidal barrages thus reducing perceived flood risk. These uncertainties necessitate that an element of caution be adopted when interpreting the evidence and results of this assessment, including the summary in table 4.1, Section 4.6.

4.5.6 *Summary: coast and seas*

In the open seas, fisheries policies, and especially fisheries quotas are most likely to enable accommodation of climate change by affecting the ability of biodiversity to respond. Any modification of fisheries policy to account for the impacts of climate change will have a major impact on fish, but also impact on other biodiversity associated with the open seas.

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In coastal areas, flood-defence policy will have the most important impact on the extent to which biodiversity can accommodate climate change. Many areas of important habitat could be lost if coastal defence works are placed around much of the coasts, since they will be squeezed between rising seas and hard defences. Visitor pressure on many coastal areas may increase in response to warmer temperatures and may adversely affect biodiversity due to increased disturbance and loss of habitat to development.

4.6 Overview of Indirect impacts

Table 4.1 summarise the opportunities and threats for biodiversity that arise from the likely indirect effects of climate change which we have identified. There are many uncertainties but these indirect impacts are a result of human responses to climate change and are therefore potentially open to intervention and adaptation.

Table 4.1 Summary of indirect effects of climate change on biodiversity

Sector	Opportunity	Threat
Agriculture	<p>Benefits to farmland birds of increase in flower crops and winter stubbles</p> <p>Habitat diversity increased in arable areas by introduction of short rotation coppice and grassland</p> <p>Agri-environment schemes provide opportunities for targeted action on biodiversity, habitat creation and ecological networks</p>	<p>Impacts on farmland birds of expansion of intensively managed crops and changes to timing of management activities (autumn sowing, earlier harvesting)</p> <p>Impacts on biodiversity of some biofuel production systems (Miscanthus and oil seed rape)</p> <p>Loss of semi-natural farmland habitat from expansion of short rotation coppice</p> <p>Decline in lowland livestock and mixed farming systems and intensification of marginal habitats</p> <p>Uncertain impacts of novel crops and land use (e.g. vineyards and orchards)</p>
Water and wetlands	<p>Creation of wetland habitats for water storage and flood control</p> <p>Integrated catchment management for protection of water resources</p>	<p>Drying of wetland habitats and low flowing rivers due to increased water abstraction</p> <p>Fragmentation of river habitats by artificial structures (impoundments, flood control and hydro-electric schemes) affecting biodiversity (e.g. fish migration)</p> <p>Increased disturbance, pollution, turbidity due to expansion of recreation use</p>

Sector	Opportunity	Threat
Woodland and forestry	<p>Creation of woodland habitats and ecological networks</p> <p>Greater diversity of habitats in woodlands due to increased management</p>	<p>Inappropriate woodland management due to greater emphasis on timber production, including biomass fuels</p> <p>Loss of semi-natural habitat due to expansion of productive woodlands</p>
Towns and cities	<p>Strategic planning for sustainable development (carbon neutral) incorporating biodiversity objectives (e.g. ecological networks, habitat creation).</p> <p>Biodiversity included within designs for buildings and open spaces (trees for shading, green roofs etc)</p> <p>Protection and creation of wetland habitats as part of flood management and sustainable urban drainage systems</p>	<p>Intensification of land use in urban areas as a consequence of policies for increased energy efficiency</p>
Coasts and seas	<p>Creation of coastal habitats through managed re-alignment and construction of artificial structures for flood defence</p>	<p>Inappropriate setting of fisheries quotas exacerbates climate impacts on marine biodiversity</p> <p>Increased loss of coastal habitats due to construction of flood defences</p> <p>Loss of habitats and increased disturbance due to tourism development</p> <p>Loss of habitats and disturbance due to exploitation of renewable energy (tidal barrages and wind farms)</p>

5 Other causes of biodiversity change

In addition to climate change, many other pressures impact on biodiversity (Millennium Ecosystem Assessment, 2005) and they are summarised briefly in this review, because they may exacerbate the effects of climate change or, in rare cases counteract them. Reduction or removal of pressures that impact negatively on biodiversity can increase the resilience of habitats and associated species so they are able to cope with effects of climate change.

At a global level, land-use change is predicted to have the greatest effect on the biodiversity of terrestrial ecosystems followed by climate change, nitrogen deposition, biotic exchange (the deliberate or accidental introduction of plants and animals to an ecosystem), and elevated carbon dioxide concentrations (Sala *et al.*, 2000). For freshwater ecosystems biotic exchange is considered to be a more important driver of biodiversity change (Sala *et al.*, 2000). Fishing has a major impact on the marine environment in UK waters (Defra, 2005).

At a UK level, the 2005 reporting round for UKBAP priority species and habitats asked lead partners to identify the top five threats to the species or habitat over the next five years. This process identified 15 threats to priority habitats and species in addition to climate change (Defra, 2006b). Habitat loss, infrastructure development, changes in management practices, climate change and invasive species were identified as the top five threats to priority habitats (Figure 5.1). Habitat loss and degradation (particularly due to agriculture or changes in management practice) continues to be a significant threat for a high proportion of species and habitats. Woodland management and change in habitats due to succession are also of concern for some species. Infrastructure development (mainly housing and development on the coast) is emerging as a concern for species and habitats. Two thirds of habitat Lead Partners identified this as a significant threat. This underlines the importance of the protected sites network and the crucial role of the planning system in safeguarding biodiversity. Global warming is an emerging threat for a high proportion (47%) of habitats.

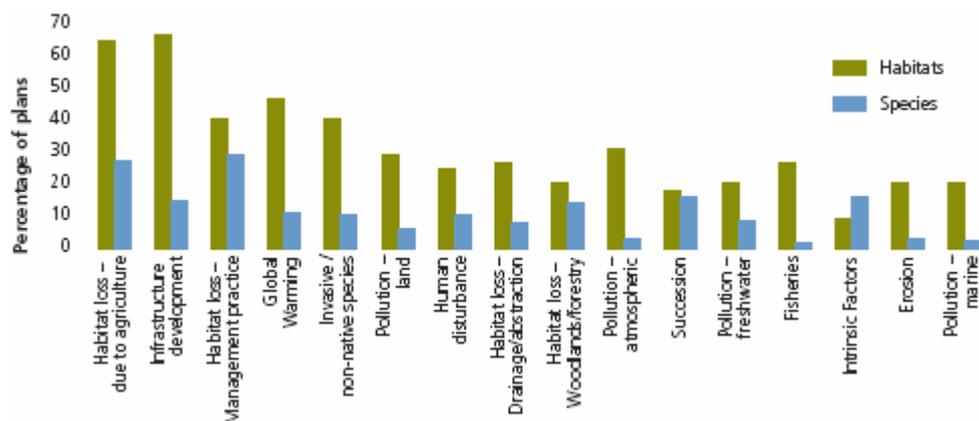
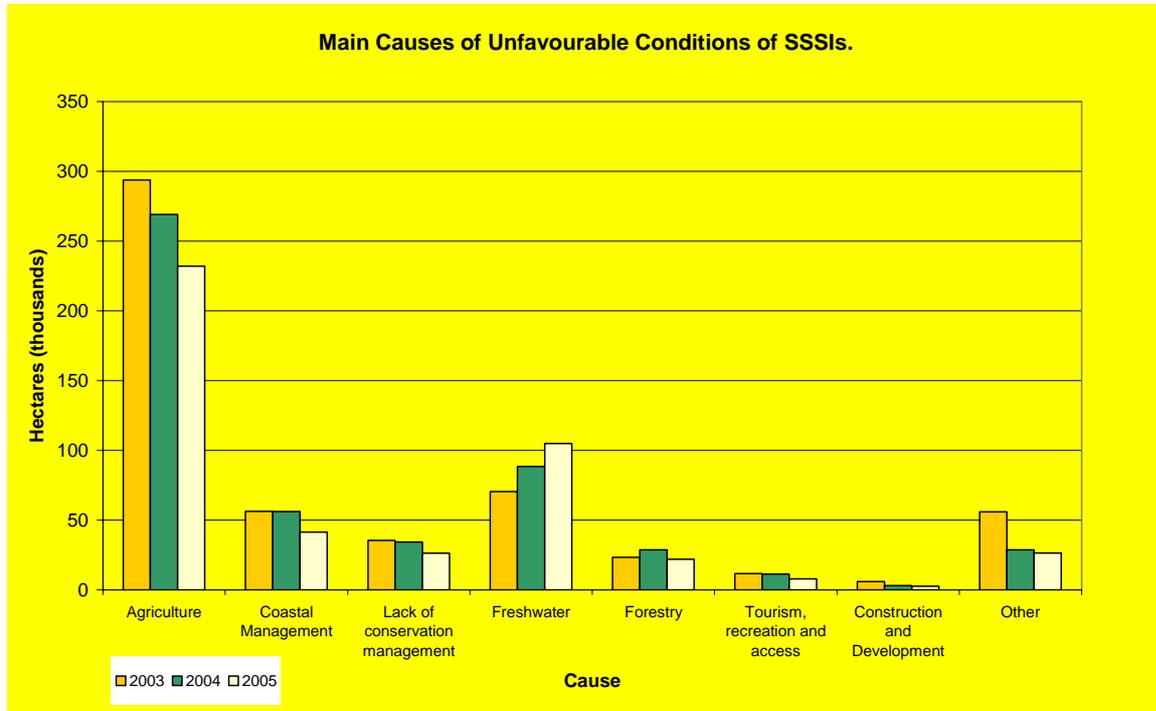


Figure 5.1 Current and emerging threats faced by priority habitats and species (Source: Defra 2006b)

5 Other causes of biodiversity change

The percentage of SSSIs in favourable condition has risen from 57% to 72% between 2003 and 2006 (Defra, 2006c). The main reasons for unfavourable condition are summarised in Figure 5.1.



- **Agriculture:** Inappropriate conservation management under the Countryside Stewardship Scheme or Environmentally Sensitive Area agreements; Fertiliser use; Inappropriate stock-feeding; Overgrazing; Under-grazing; Moor burning; Inappropriate cutting/mowing; Pesticide/herbicide use
- **Coastal:** Coastal squeeze; Inappropriate dredging or coastal management; Sea fisheries
- **Lack of conservation management:** Inappropriate pest control, scrub control or weed control
- **Freshwater:** Water pollution - agriculture/run off or discharge; Drainage; Floods; Water abstraction; Siltation; Inappropriate ditch management, water levels or weirs dams and other structures; Inland flood defence works; Invasive freshwater species; Fish stocking
- **Forestry:** Deer grazing/browsing; Forestry and woodland management
- **Tourism, recreation and management:** Game management - pheasant rearing or other; Vehicles – illicit or other; Public access/disturbance
- **Construction and development:** Earth science feature obstructed or removed; Planning permission (general or other mineral and waste); Peat extraction
- **Other category:** Air pollution; Fire – other; Military

Figure 5.2 The main causes of unfavourable condition of SSSIs (Defra, 2006c)

Scientific evidence on the relative impact of climate change and other pressures on biodiversity and their interactions is often lacking. This is particularly true in the case of interactions between multiple factors, although the patterns of change caused by some individual drivers is understood. For the sake of brevity, not all non climate change causes of impacts on biodiversity are included here. Drivers of change in biodiversity were included if their effects are widespread across the UK, or common across all sectors within the EBS. The commonest non climate change pressures

5 Other causes of biodiversity change

causing impacts on biodiversity reviewed here are: habitat destruction, changes in management practices, non native species, air pollution and over-exploitation.

5.1 Habitat destruction.

Habitat destruction resulting from, for example, development, change in land use or water abstraction can lead to a number of other problems in addition to the direct loss of habitat area. These include habitat fragmentation, reduced carrying capacity, reduced resilience to disturbance, reduced opportunities for dispersal across landscapes.

The UK BAP identified habitats, extents and status, and showed that nearly all of the broad and priority habitats had suffered a degree of loss or fragmentation, caused by a variety of factors. The present rate of direct habitat destruction is low by recent historical standards but this could change if socio economic drivers of land use change under a changing climate.

The dramatic losses of habitat that occurred in the second half of the 20th century means that habitat patches are often small and fragmented in much of England. The lowland heaths in Dorset provide a well-documented example of this decline in area and fragmentation. In 1811 there was 30000 ha of heath (Moore, 1962), this had declined to 5141 ha by 1981 (Webb, 1990). As the area of heathland declined they have also been fragmented. In 1759 the heaths of the Poole Basin in Dorset consisted of about 10 large blocks (Haskins, 1978). By 1978 fragmentation had increased to 768 pieces (Webb and Haskins, 1980).

More fragmented habitats are likely to be more vulnerable to climate change due to decreased resilience, decreased dispersal routes and loss of ecosystem function. Small isolated areas of habitat may contain populations of species, which are too small to be viable in the long term because of their vulnerability to population fluctuations.

5.2 Changes in management practices

Management practices are influenced by practicality, desired outcomes and policy or socio economic pressures and financial incentives. These can impact on biodiversity in positive or negative ways at a range of spatial and temporal scales. There is evidence that changes in management practices have had detrimental effects on biodiversity. Management practices can exacerbate impacts or contribute to adaptation to climate change. The management of protected sites is especially important as it is aimed at achieving favourable condition, or improving habitat quality in terms of structure and species supported. Examples of changes in management practices that are detrimental to biodiversity include the cessation of grazing on chalk grassland and lowland heaths (e.g. English Nature, 2003; Webb, 1990; Rose *et al.*, 2000; Gibson and Brown, 1991), leading to a loss of distinctive species in these habitats and an increase in successional species. On the other hand, the over-grazing of upland heaths (Welch, 1984; Welch, 1986; Welch and Scott, 1995) has led to a decrease in the distinctive flora of these habitats. The intensification of agricultural management, such as the change from spring to winter sown crops and the increased use of fertilisers, herbicides and pesticides has led to wide-ranging

changes in the biodiversity of agro-ecosystems, including a decline in farmland birds and rare arable weeds (e.g. Hart *et al.*, 2006; Gregory *et al.*, 2004; Benton *et al.*, 2002; Marshall *et al.*, 2003; Chamberlain *et al.*, 2000). Agri-environment schemes are now starting to reverse some of these changes. The abandonment of coppicing and pollarding in woodlands (Peterken, 1981; Rackham, 2003) has led to a decline in ground layer vegetation and associated animal species, which have adapted to the habitats created by these practices over centuries.

5.3 Non-native species

Biological invasions by non-native species are a significant component of human-caused global environmental change (Hulme, 2003; Sala *et al.*, 2003; McNeely *et al.*, 2001). Impacts of non-native species on native biodiversity may result from the competitive exclusion of native species, but dilution of native genetic stock through hybridisation is also a factor in some cases; indirect effects can also result from a change in ecosystem function, such as the exclusion of light at the surface in the case of *Rhododendron ponticum*.

Only a small proportion of non-native species currently cause very serious ecological impacts. However the general decline in UK biodiversity and the potential effects of future climate change may increase the susceptibility of ecosystems to invasion (Manchester and Bullock, 2000). This is not inevitable and it will depend on what adaptation measures are taken to address climate change, which is discussed in Section 6. Climate change may present conditions favoured by some non-natives, enabling them to thrive and spread, but this is only a problem if there are adverse effects on other species (see Section 6).

Hill *et al.* (2005) lists 2721 non-native species and hybrids that occur in England. Flowering plants are the most numerous group of terrestrial and fresh water non-native species in England, and in terrestrial habitats the Hemiptera (bugs and aphids) and Coleoptera account for the most non-native species. In marine habitats, the red algae group *Rhodophyceae* contains the most non-native species. The majority of non-native marine organisms, animals and microbes have been introduced to England accidentally, while terrestrial and freshwater plants have mostly established by escaping from cultivation. There are geographical and habitat specific effects. Except for vascular plants, there is a marked difference in numbers of non-native species recorded in the south and in the north of England, with more species in the south than the north. In terrestrial habitats, wetlands (bogs, fens and marshes) have the lowest number of non-native species (Hill *et al.*, 2005).

Hill *et al.* (2005) list only four animals that have a strong positive economic effect: common pheasant (*Phasianus colchicus*), greylag goose (*Anser anser*), red-legged partridge (*Alectoris rufa*), and the predatory beetle *Rhizophagus grandis*, but many plants of wild or wild-type seed origin are cultivated, especially by foresters and these have a strong positive economic impact.

The most studied species are non-natives that have established and caused serious detrimental ecological impacts and include the ruddy duck (*Oxyura jamaicensis*), Canada goose (*Branta canadensis*), grey squirrel (*Sciurus carolinensis*), north American signal crayfish (*Pacifastacus leniusculus*), zander (*Stizostedion*

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Lucioperca), rhododendron (*Rhododendron ponticum*), Japanese knotweed (*Fallopia japonica*) and the New Zealand flatworm (*Artiosthia triangulata*) (Manchester and Bullock, 2000).

Increasing deer populations, including the non-native muntjac (*Muntiacus reevesi*) and fallow (*Dama dama*; resident since Roman times) are a major cause for concern within woodland conservation (Fuller and Gill, 2001). Non-native aquatic plants can choke rivers and wetland features, cause problems with over-shading other species and eutrophication, eventually displacing and excluding native species, and possibly imposing a detrimental effects on the quality of the water column.

Climate change could have a direct species-specific impact on many invasive species. In particular, species which are currently unable to survive over the winter, or for which this is a major control on population size, may be able to increase in abundance or spread further north. This is one explanation that has been proposed for rising deer populations (Fuller and Gill, 2001).

In the marine environment, there is evidence that establishment of non-native species is facilitated by climate change (Stachowicz *et al.*, 2003). For example *Crassostrea gigas* has spread from aquaculture and is now thriving and having major ecosystem effects in the Netherlands (Hiscock *et al.*, 2006) and the rapid spread of the American slipper limpet *Crepidula fornicata* has been attributed to climate change effects (Riese *et al.*, 2006; Thieltges *et al.*, 2004).

5.4 Air pollution

Many semi-natural habitats are naturally nutrient poor and support assemblages of plants that are adapted to these conditions. Large parts of England receive excess levels of nutrient nitrogen from atmospheric nitrogen deposition (Figure 5.3). Eutrophication as a result of atmospheric nitrogen deposition tends to allow faster growing species of more mesotrophic environments to out-compete the slow-growing species typical of low nutrient sites. The Countryside Survey programme (Smart *et al.*, 2003) and The New Plant Atlas (Preston *et al.*, 2002) show that nutrient enrichment from air pollution (together with agricultural applications) is a major cause of floristic change across the UK, and these findings are supported by a range of other studies and reviews (Hodgson, 1986; McCollin *et al.* 2000; Stevens, 2005, Hartley and Mitchell, 2005; Mitchell *et al.*, 2005, NEG-TAP, 2001; Stevens *et al.*, 2004; Carroll *et al.*, 2003).

In the late 19th and for most of the 20th centuries high emissions of oxides of sulphur (SO_x) led to acid deposition, which caused widespread direct damage in many habitats and increased weathering of toxic metals, driving changes in epiphytic plant community composition and changing soil and freshwater chemistry (Bates, 2002; Crittenden and Read, 1979; Farmer *et al.*, 1991; Adams and Preston, 1992). Acid deposition halved between 1986 and 1997 (NEG-TAP, 2001) resulting in a widespread increase in soil pH (Kirby *et al.*, 2005) and early signs of biological recovery (NEG-TAP, 2001).

This decline in acidic pollution led to a rapid expansion of some lichen species and increase in the abundance of moths associated with lichens (NEG-TAP, 2001; Bates,

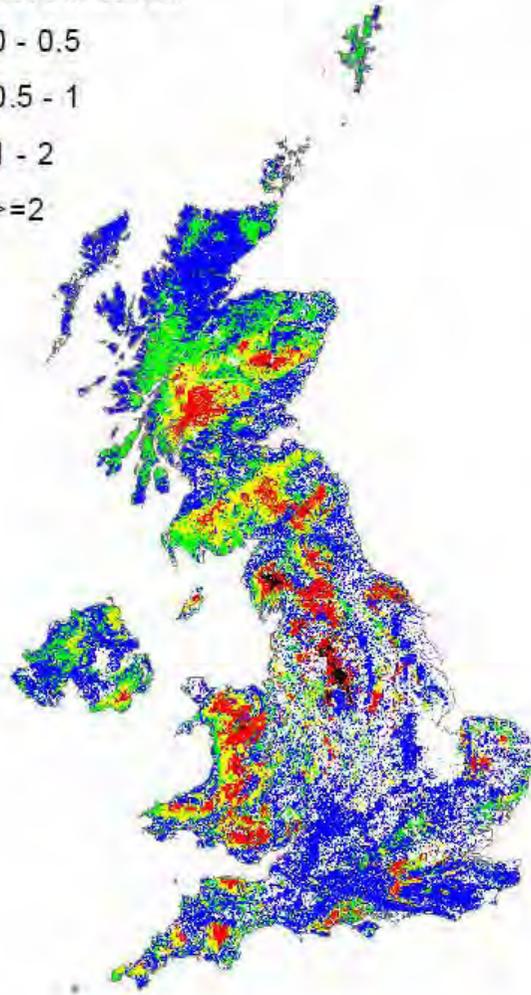
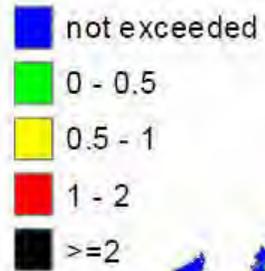
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2002; Conrad *et al.*, 2004). Braithwaite *et al.*, (2006) report an increase in woodland vascular plant species associated with base rich conditions. There is clear evidence of chemical change in freshwater systems and the first stages of biological recovery have been detected (NEG-TAP, 2001), although improvements in Great Britain have not been as marked as elsewhere in Europe (Stoddard *et al.*, 1999). Widespread acidification also affected acid-sensitive soils and as yet there is little direct evidence of recovery despite the reduced deposition, possibly reflecting an extreme loss of base elements which may not be recoverable (NEG-TAP, 2001). As SO_x emissions continue to decline, nitrogen rather than SO_x is predicted to be the major contributor to acidification by 2010 (NEG-TAP, 2001). The response of biodiversity to a decline in SO_x will depend on the interacting effects of N and SO_x pollution and which pollutant they are more sensitive to (Stevens *et al.*, 2004).

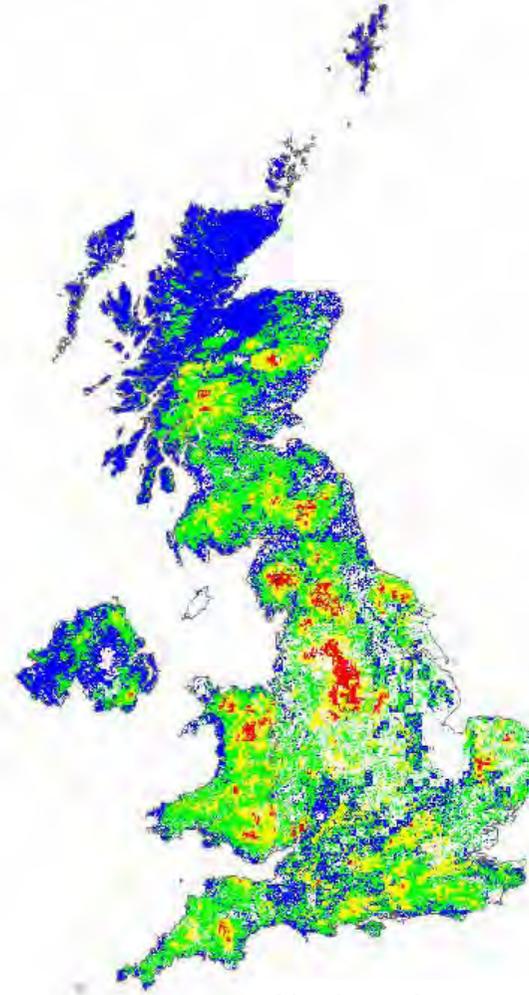
Ground level ozone concentrations regularly exceed recognised thresholds for effects on vegetation and human health throughout the UK (NEG-TAP, 2001). While peak concentrations declined by 30% between 1986 and 1999, baseline ground level ozone concentrations are rising. Symptoms of ozone damage have been well-documented for some species, but there remains much uncertainty about long-term impacts on perennial plants and plant communities (Ashmore, 2005). Interactions with climate change are therefore hard to predict at present. It is a potentially important issue, as the conditions that favour ozone formation (sunny, warm and dry) are predicted to become more common during summer over much of the UK with climate change (Hulme *et al.*, 2002).

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Exceedance $\text{keq ha}^{-1} \text{ year}^{-1}$



Acidity



Nutrient nitrogen

Figure 5.3 Exceedance maps for terrestrial habitats for acidity and nutrient nitrogen using deposition data for 2002-04 (using 1km 5th percentile critical loads) (Source CEH)

5.5 Over exploitation of wild populations

Over-exploitation can impose pressures on habitats and associated species, which increases their vulnerability to other pressures, including climate change.

Over-exploitation is driving changes in biodiversity particularly in the Coasts and Seas sector. Over-fishing at sea is having profound effects upon the marine communities and the physical structure of the seabed. Large predatory fish such as common skate and cod have declined in abundance, resulting in “fishing down the food chain” (Pauly *et al.*, 1998; Kaiser *et al.*, 2000). Fishing activity affects other species both directly and indirectly. A large biomass of non-target species are caught as bycatch (Pauly and Christensen, 1995) and changes in abundance of fish affects species at other trophic levels (Dayton *et al.*, 1995), such as predatory sea birds (Rindorf *et al.*, 2000).

Over-exploitation and climate effects will interact to increase the impact of climate change on the marine ecosystem (Frederiksen *et al.*, 2004). For example, climate-related changes in plankton communities have been shown to lead to low recruitment of cod in the North Sea, this exacerbating the effects of over-fishing (Beaugrand *et al.*, 2003). There is evidence that in the southwest English Channel, pilchard (sardines) and herring have alternated in abundance in the past in response to climate but over-fishing of herring has led to a permanent decline in this species (Southward *et al.*, 2005).

5.6 Summary of other pressures on biodiversity

Non-climate change pressures on biodiversity may be positive or negative, but the negative effects may be exacerbated by climate change. Negative impacts include shifts in community distribution, loss or reduction in available habitat and associated species, restricted dispersal capacity due to habitat fragmentation, competitive exclusion due to invasion by non-native species, and changes in the structure and species diversity of some habitats due to inappropriate management. Positive impacts include enhanced habitat condition and species diversity due to favourable management, creation or restoration of habitats, increased and enhanced dispersal routes, and improved survival of endemic species following implementation of control of pollution and of non-native species.

The non-climate change impacts briefly covered here are:

- **Habitat destruction** causes fragmentation and a reduction in extent of the habitat. Small areas of habitat are more susceptible to additional pressures including those associated with climate change. Remnants of habitats can offer opportunities, as sanctuaries or as sources of pioneers or colonists if changing conditions or creation of habitat favours their survival or dispersal.
- **Change in management practices** can have both positive and negative impacts on biodiversity and there are opportunities for biodiversity under a changing climate by developing and promoting good practice.
- **Non-native species** may cause change in community structure (through displacement or interference), loss of species and potential changes in

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ecosystem function, with greater sensitivity of some habitats when under increased stress due to climate change. There is potential for increased diversity where they compliment or substitute losses due to climate change.

- **Air pollution** (nitrogen, oxides of sulphur, carbon dioxide and ozone) can cause changes in soil conditions, loss of species, shifts in community structure and ecosystem function.
- **Over exploitation** can impose pressures on habitats and associated species, which increases their vulnerability to other pressures, including climate change.

6 Adapting to climate change

6.1 Introduction

The evidence (Section 3; Table 3.12) is clear that climate change is starting to have direct effects on many of the habitats and species that the England Biodiversity Strategy seeks to protect, restore and enhance and that these effects will increase. The indirect effects of climate change may be at least as serious as the direct ones (Section 4). The magnitude of the potential impacts could compromise the feasibility of achieving the aims of the EBS and government policy commitments, including those arising from the agreement to halt biodiversity loss by 2010 (Gothenburg European Council Meeting, 2001). Policy and management responses to reduce adverse impacts of climate change on biodiversity should therefore be a high priority for government and other stakeholders.

Adaptation is about increasing the resilience and therefore reducing the vulnerability of natural systems so that they can accommodate and respond to climate change. Climate change forecasts contain significant uncertainties. The precise relationships between atmospheric CO₂ concentrations and global climate are not known; climate models, and the emissions scenarios on which they are based, can only provide a range of outcomes with associated probabilities; and different global climate models have significantly different projections beyond the 2050s. Models of ecological and socio-economic impacts are based on these forecasts and are simplistic in comparison to the multitude of factors which could affect responses. For example, an increase in the frequency of extreme events, rather than average projections of change, may cause the greatest impacts and pose the biggest challenge to the development of adaptation. Whilst much emphasis is given to the direct impacts of climate change on biodiversity, the indirect impacts arising from the climate-related responses of agriculture, forestry, water management, town and country planning, coastal management, fishing and other land-based and marine activities has the potential to be even greater. Hopes that models can project climatic changes with certainty and enable predictive responses to be designed with precision are unlikely to be fulfilled for the foreseeable future.

Adaptation strategies must, therefore, accommodate uncertainty so that 'no regrets' decisions are made which enable the widest biodiversity to survive and evolve. The emphasis should be on identifying adaptation measures which will deliver other positive outcomes in addition to climate change adaptation, be valuable under all realistic scenarios or at least have minimal adverse consequences ('win-win', 'no regrets' and 'low regret' measures - see *Terminology*, Box 6.1). Actions known to cause jeopardy need to be reduced or avoided, and those which increase stability and promote ecosystem function should be maintained or enhanced. Resilient natural systems will not only benefit biodiversity, but also human society in terms of the 'services' that ecosystems provide: soil conservation, clean air and water, high quality food, and economic and social benefits that add to the quality of life. Faced with the challenges of climate change, adaptation strategies need to be implemented urgently to cope with the current and likely future rate of change, the extent of habitat fragmentation, the scale of adaptation action required and the timescale needed for this to take effect (for example, newly created habitats may take many decades to

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develop to maturity). Adaptive management techniques need to be matched to the challenge. Failure to adopt a precautionary approach in taking action would present significant risks to both future biodiversity and the continuing provision of ecosystem services.

The concept of 'adaptive management' (Box 6.1) provides a risk management framework, which has been promoted by, for example, the UK Climate Impacts Programme (www.ukcip.org.uk; Willows and Connell, 2003). Under adaptive management, the intention is to incorporate sensitivity and retain flexibility, so that responses can be developed and improved as new methods become available, new impacts are revealed or unforeseen situations arise. The application of adaptive management for biodiversity conservation in a changing climate has been presented in a briefing paper published jointly by IUCN, WWF, RSPB and EN (http://www.iucn.org/themes/climate/wl/documents/cc-nature_adapting_for_future.pdf). A basic model for adaptive management for marine systems has been described by Mee (2005).

Much of this chapter is concerned with specific measures which can help to reduce the adverse impacts of climate change on achieving conservation objectives. It is also important to step back and recognise that climate change presents a challenge to some of the underlying principles of nature conservation in England over the last 60 years. Many of our current approaches to conservation developed over a period when the major threats to biodiversity were changes in land use and management, such as agricultural intensification and afforestation with non-native species. The objective of conservation strategies was consequently to protect or restore the diversity of habitats and species which thrived under earlier, traditional management practices.

Box 6.1 Terminology

A number of words and phrases have taken on specific meanings within the context of the climate change research and policy communities.

Accommodation is used by some authors to refer to strategies facilitating movement of species across the countryside and over barriers, both natural and man-made, such as roads and towns. Examples of accommodation actions might be to develop nature reserve management practices to encourage the arrival of particular incoming species; or to increase landscape connectivity in order to link fragmented habitats by designating 'adaptation zones'. (adapted from Backer, de Pous and Watts, 2006)

Adaptation measures are those intended to increase the ability of systems to respond to climate change with a minimal loss of desirable properties or functionalities (IPCC, 2001a). This encompasses both accommodation of change and resilience to change.

Adaptive management is a flexible approach for handling uncertainties. It involves putting in place incremental adaptation options, rather than undertaking large-scale adaptation in one fell swoop. (www.UKCIP.org.uk; accessed 3 December 2006) It is explained in a biodiversity context by Defra (2006).

Mitigation aims to reduce releases of greenhouse gases into the atmosphere including by sequestering carbon in natural or artificial carbon stores such as wetlands and gas permeable geological strata (IPCC, 2001b; Defra, 2006c). Mitigation itself is outwith the scope of this report, however the effects of mitigation measures on biodiversity are covered as 'indirect impacts' of climate change.

No regrets. Adaptation options (or measures) that would be justified under all plausible future scenarios..... and continue to be worthwhile irrespective of the nature of future climate. (Willows and Connell, 2003).

Resilience. Within the climate change context resilience is used in a general sense to describe ecosystem properties which increase the chances of current biodiversity interest continuing to be maintained under climate change. As such it encompasses two concepts which are sometimes separated in academic ecology, where resilience means 'the speed with which a community returns to its former state after it has been disturbed' and 'resistance' is the ability of a community to avoid displacement from its present state by a disturbance (Begon, Harper and Townsend, 1996).

Win-Win. Options which reduce the impacts of climate change and have other environmental, social or economic benefits (Willows and Connell, 2003)

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Issues of land use and management remain important, but the challenge of climate change requires a paradigm shift in attitudes to conservation. Building resilience and accommodating change are both vital components of an adaptation strategy as well as specific measures to directly tackle adverse impacts. Species characteristic of one part of the country may survive in places where they were not previously found. Combinations of species may change as some disperse more quickly than others and consequently track climatic conditions more closely. Coastal features may disappear altogether and new ones emerge in different places. As the twenty-first century progresses it will become increasingly difficult to maintain the *status quo* or recreate habitats and landscapes familiar from earlier periods. At present a high priority is typically given to maintaining local species, ecotypes and provenances in the places they are currently found. There may be circumstances in which this is not viable in future. Focussing on only local genotypes may even be counterproductive in some situations, as high levels of genetic variation increase the chances of populations evolving and adapting to changing environments (Gregory *et al.*, 2006). On this and other issues, there are a range of views amongst experts, but it is important to start considering options and gathering the necessary information to allow decisions to be made.

It is important to maximise opportunities to increase biodiversity as well as to address threats. Climate change does not represent a uniform threat to all species and habitat. Building resilience and accommodating change are both vital components of an adaptation strategy as well as directly tackling adverse impacts. Some habitats and species are likely to be relatively robust to modest climate change and some currently rare species are expected to become more common under climate change. Whilst the species composition of some priority habitats may change, they may remain species-rich and valued by local communities.

There is therefore a need for a new shared vision for biodiversity conservation in the decades ahead. This vision will need to be reflected in policy targets and objectives that take into account dynamic baselines and ecosystem properties such as resilience, as well as species-specific and habitat-specific ones. It is essential that the evidence base provided by research and monitoring is appropriate to support this and accessible through appropriate knowledge transfer activities.

6.2 Adaptation principles

Adaptation (Box 6.1) of biodiversity policy and management to minimise the adverse impacts of climate change on biodiversity has been debated by a large number of international bodies, including recently the IUCN, the European Platform for Biodiversity Research Strategy (EPBRS, 2005), the European Environment and Sustainable Development Advisory Councils (EEAC, 2005), and the EU Nature Directors (2005). These issues were also addressed at the Eighth Conference of the Parties to the Convention on Biological Diversity (Decision VIII/30, www.biodiv.org/doc/meetings/cop/cop-08/official/cop-08-31-en.pdf).

The EBS climate change adaptation workstream members have identified four key principles for adaptation to climate change, aimed at reducing vulnerability and managing for uncertainty:

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- Reduce direct impacts
- Reduce indirect impacts
- Increase resilience
- Accommodate change

These are generic principles and their practical application can be summarised as six measures for adaptation.

- Direct management to reduce impacts of climate change
- Promote dispersal of species
- Increase available habitat
- Promote conditions for ecosystem functioning
- Optimise sectoral responses to climate change for biodiversity
- Continue to reduce pressures not linked to climate change

In addition three key underpinning requirements enable these measures to be developed and implemented:

- Monitoring and surveillance
- Development of the evidence base
- Knowledge transfer and communication

These adaptation measures are discussed further in the rest of this chapter, together with illustrations of applications in each of the EBS sectors.

6.3 Adaptation measures

6.3.1 *Direct management to reduce impacts of climate change*

Specific interventions or changes in management may reduce adverse impacts of climate change on aspects of biodiversity (these can be site based operations for localised effects, or they can be applied across wider areas). For example, most plant species can survive at warmer sites than they typically occur in naturally (as can be observed in botanic garden collections of alpine plants). In natural conditions they are excluded by competition with species that grow faster and larger at higher temperatures (Morecroft and Paterson, 2006). In some cases reducing competition may allow threatened species to persist, for example, by changing grazing regimes, preventing spread of competitor species or even direct removal of competitors in the vicinity of particularly threatened individuals. Manipulating microclimate, by modifying vegetation height or canopy structure is another option, perhaps more suitable for invertebrates and other small animal species. Soil and surface temperature decrease with increasing vegetation height (Green *et al.*, 1984) and this offers opportunities for intervention by management; for example, allowing grassland swards to grow taller will create cooler conditions at the soil surface. Planting shade trees may also provide cooler microclimates for some species. In some habitats, water supply can be manipulated through changing drainage or water level which may offer potential to offset some of the effects of drier summers. Approaches like these will usually need to be considered and implemented at a local level, with an element of trial and error, at least for the immediate future. There will also need to be

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an assessment of the feasibility for each, in the light of available resources and a cost-benefit analysis. For example, the direct removal of individual competitors is only likely to be viable for very threatened species at a small number of sites.

6.3.2 *Promote dispersal of species*

If species approaching their climatic limits cannot adapt to the new climate and cannot be maintained in their present locations by management, they will only survive if they move into new areas where the climate is suitable. Dispersal of this sort can take place at a range of scales: northwards movement between geographical regions, altitudinal movement and possibly local movement between different microclimates (such as slopes of different aspects). In the fragmented landscape of much of England, areas of suitable habitat for threatened species may be widely spaced and separated by areas of developed or intensively managed land, making the colonisation of new sites unlikely unless the species are very mobile, particularly for the longer range dispersal between geographic regions. Accommodating change therefore requires 'permeable' landscapes, which allow dispersal of species between habitat patches. This is termed functional connectivity and does not necessarily require physical linkage (Catchpole, 2006). Functional connectivity also increases resilience by allowing recolonisation following local one-off extinctions (for example, from fire or a pollution incident) and promotes outbreeding.

The concept of connectivity across landscapes is well accepted but the best means of determining and achieving it will depend on specific circumstances and the organisms of interest. Three main strategies have been proposed to increase connectivity: 'corridors', 'stepping stones' and improving the quality of the matrix in which habitat patches are found. Corridors are linear and directly link habitat patches; stepping stones are small patches of suitable habitat in a landscape of unsuitable habitat, which reduce the distance between larger areas of a habitat. Corridors have been the best studied and there is evidence that a wide range of species can move along them (e.g. Beier and Noss, 1998, Haddad *et al.*, 2003). However, recent reviews (Donald, 2006; Davies and Pullen, 2006; Hulme, 2006) have concluded that corridors have limited advantages for some groups.

The matrix surrounding semi-natural habitat patches is important in promoting the dispersal of species between patches (Baum *et al.*, 2004; Catchpole, 2006; Castellon and Sieving, 2006; Donald and Evans, 2006). In practice, in the English context, this approach is likely to include protection and enhancement of linear features and Donald and Evans (2006) include hedgerows, ditches and field margins as matrix features alongside less intensive management and specific measures to benefit wildlife (such as planting bird seed mixtures, which can be supported under agri-environment schemes). Catchpole (2006) presents an approach to target habitat creation in the areas where it can contribute most to developing an ecological network, for example the planting of new woodlands may be most effective if targeted to fill in gaps between existing woodlands. The principle of connectivity also applies to marine systems although the specific issues are different and these are discussed in Section 6.3.5.

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Increasing landscape permeability may increase the risks to biodiversity from non-native invasive species and the situation will need to be monitored, with control measures put in place if necessary. Most non-native species which establish themselves in the UK are not invasive or detrimental to wider biodiversity (Hulme, 2006). Some of these species may positively enhance biodiversity, for example, colonisation of some English habitats by currently rare migrant butterflies. One of the best means of reducing risk from invasive plant species is the restoration of stable semi-natural communities, as these are less susceptible to invasion than more disturbed, early successional areas (Bakker and Wilson, 2004, Donald and Evans, 2006; Hulme, 2006). There is however evidence that climate change, particularly drought, may cause an increase in gaps and ruderal species in some vegetation types including ex-arable grassland (Grime et al. 2000, Morecroft et al., 2004, Sternberg et al., 1999). Control of non-native species may therefore be partially dependent on effective management response within semi-natural habitats.

There are limitations to promoting dispersal. The least easily dispersed species, including many slow growing perennial plant species, will not be able disperse northwards at the rate at which climate is changing. In some circumstances translocation - the deliberate introduction of a species to a new location - may be considered necessary (Hulme, 2005). Guidelines for translocation have been published by the IUCN (<http://www.iucn.org/themes/ssc/publications/policy/transe.htm>). Translocation is not widely accepted as a general policy at present, because of the costs and risks associated with it. It may however need to be considered for slow dispersing species which are unlikely to be able to persist in their present locations. One factor which may need to be taken into account is the extent of the species range outside the UK and the significance of the threat the species faces in these other areas relative to the UK.

6.3.3 *Increase available habitat*

Increasing habitat size needs to be viewed, along side promoting dispersal, as part of a 'landscape scale approach' – taking into account not just the size of particular patches but the ways in which they interact with each other (Catchpole 2006). Habitat creation or restoration should reduce fragmentation and promote permeability of the landscape.

Increases in habitat area can be achieved by expanding the area occupied by existing habitat patches and by increasing the number of discrete areas of habitat. Both larger patches of habitat and more patches have advantages. Larger patches support larger populations which are more resilient to extinction during extreme climatic events such as droughts and floods. Extending existing areas can create a buffer between agricultural land and protected areas and help to safeguard them from other pressures, for example spray drift and disturbance. It may also be a good strategy to promote colonization of plants and animals from the existing habitat. More patches may contribute to the possibility of species dispersal into new areas and may also allow recolonisation following local extinctions. For example, there is evidence that new habitat for the marine honeycomb reef worm, *Sabellaria alveolata* in the form of artificial structures has contributed to its re-establishment by acting as a larval source for natural shores, in addition to acting as a 'stepping stone' for it to

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colonise new areas (Frost *et al.*, 2004). Increasing habitat size does therefore need to be seen alongside 'promoting dispersal' as part of a landscape scale approach.

An important aspect of increasing area is to increase the range of soil types and topographical variations in microclimate covered by a habitat in a region. This in turn increases the probability of species being able to persist in localised pockets of suitable conditions, sometimes termed 'microclimate refugia' (Noss, 2001). The extent of this variation can be considerable. Oliver (1992) measured superficial soil temperatures up to 17°C higher on south-facing slopes than on north-facing slopes, on sunny days. On a cold night air temperatures at the bottom of a slope may fall several degrees compared to those at the top because of cold air drainage, creating a 'frost hollow'. Water content and availability can also vary dramatically between different soils and topographies with for example, spring lines and flushes remaining wet through the summer where surrounding areas dry out.

Increasing available habitat may be achieved by restoring degraded habitats or creating new areas of habitat. Habitat restoration and creation are already key aims of the EBS in 2006-2010 (Defra, 2006c), but explicit consideration of climate change should be incorporated into the planning stage for any specific scheme, taking into account the long term viability of the habitat in that location and its contribution to wider landscape adaptation.

6.3.4 *Promote conditions for ecosystem functioning*

Ecosystem functioning is a loosely defined concept, but can be summarised as the way biological communities operate and interact with the physical environment. It includes, for example nutrient and water cycling and energy transfers, as well as interactions between species, such as pollination and competition. The long term survival of species and habitats is dependent on these processes. Changes in climate can have a direct effect on these processes, as well as through changing species compositions of communities. For example, rates of decomposition and associated processes such as nitrogen mineralization are strongly influenced by soil temperature and water content and changes in phenology can disrupt trophic relationships (e.g. Edwards and Richards, 2004, Perrins *et al.*, 1991).

Ecosystem functioning is not usually susceptible to direct intervention, but environmental conditions can sometimes be manipulated to promote particular processes. This is particularly true where ecosystem function is dependent on maintaining particular physical conditions. So, for example, maintaining water levels in wetlands maintains the anoxic conditions in which peat accumulates. Another example is removing hard sea defences to allow erosion, deposition and successional processes in coastal and river systems.

Biodiversity and ecosystem function are linked and protecting species from other pressures will also tend to protect some ecosystem processes. For marine systems research into these links is still at an early stage (Solan *et al.*, 2006), but protecting areas from biodiversity loss due to other factors (e.g. fishing impacts on benthic communities) is nevertheless important. Stachowicz *et al* (2006) state that "*Understanding linkages between species diversity and ecosystem function is a*

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general research gap in marine ecology and is wide-open to investigations in the context of climate change”.

6.3.5 *Optimising sectoral responses to climate change for biodiversity*

Responding to climate change is necessary in many other aspects of society as well as biodiversity conservation. Changes in land use and management are inevitable (Section 4). This creates both opportunities and threats for biodiversity. For example the effect upon biodiversity of creating new woodlands as a mitigation measure depends on the species planted, management practices and the previous vegetation of the site. The planting of native species on a formerly arable site will generally enhance biodiversity, but the planting of a eucalyptus plantation on species-rich grassland would be highly damaging. In practice the choices are likely to be much more subtle – for example what is an appropriate herbicide use regime to reconcile the needs of biodiversity and energy crop production?

Strategies for adaptation should therefore consider biodiversity implications at an early stage in planning and seek solutions that are ideally ‘win-win solutions, or at least aim to avoid negative impacts (Defra 2006c). This will require policy guidance, for example to inform the planning system, but also a process of education and knowledge transfer.

6.3.6 *Reduce pressures not linked to climate change*

Section 5 summarised the range of other factors threatening biodiversity conservation, in addition to climate change, such as pollution, inappropriate management and invasive species. These issues are dealt with elsewhere and the most important are highlighted in the EBS. However, a number of issues are worth noting in the particular context of climate change.

Adaptation to climate change cannot be pursued in isolation from other pressures. The reduction of other pressures can increase the resilience of populations and communities against the impact of climate change (Hulme, 2005). Populations and communities already threatened by one pressure are almost always more vulnerable to others. Some of these pressures are relatively well understood, subject to less uncertainty than climate change and can be addressed more directly than climate change impacts themselves. For example, reducing pressure from fisheries could compensate for climate change effects and is important for the long-term health of marine ecosystems.

Interactions between climate change and other pressures - where the combined effects are greater than the sum of the parts - are possible. In such cases controlling one factor also reduces the impact of the other. The interactions between eutrophication and climate change are a good example. Changes in soil temperature and moisture affect soil nitrogen supply (see for example, Rustad *et al.*, 2001; Emmett *et al.*, 2004) and there is evidence that in some circumstances the impact of climate change on communities is mediated by competition for nutrients (Dorman *et al.*, 2004). In other circumstances nutrient limitation may restrict plant growth responses to warming and hence prevent changes in the competitive balance between species. In both cases atmospheric nitrogen deposition exacerbates the

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effects of climate change and emission reductions should lessen the impact of climate change.

Generally, the pressures that can be reduced in the most straightforward way are those that are localised, self-contained and involve only one or a few stakeholders (Holman *et al.* 2005). These include measures managed at the farm scale such as over-grazing, herbicide use, cessation of management and habitat destruction. A reduction in these types of pressure often provides quick wins. For example, reductions in pesticide and herbicide usage can bring about rapid changes in farmland biodiversity. Their impact will largely be felt by species found within the crop, those dependent on such species, or on species affected by the drift of agrochemicals. These measures can also make an impact at the landscape scale, which is important for responding to climate change, if they are co-ordinated as, in agri-environment schemes. There are other cases where reducing pressures is more of a challenge involving action at a local level but also with changes required in high level policy.

6.4 Application across and within the Sectors of the England Biodiversity Strategy

6.4.1 Generic issues: Protected sites and the wider countryside

The adaptation measures advocated in this report necessitate both a landscape scale approach and a whole ecosystem approach. They are also multi-scale and cross-sectoral. For example, promoting dispersal or development of habitat networks may require changes in management and policy relating to forestry, agriculture, soils, water, energy and development. It can also apply to a range of scales from local to continental. Mitigation measures in one EBS sector may have biodiversity impacts in another sector. For example tree planting (Woodland and Forestry Sector), may have impacts on the biodiversity of agricultural land (Agriculture Sector) where they are planted, as well as on the rivers (Rivers and Wetlands Sector) draining the catchment in which that land is located. It is therefore necessary for all stakeholders to appreciate the wider picture and to ensure that planning takes place at an appropriate level. The EBS has gone some way towards this with a landscape scale approach to management listed as a deliverable by 2010 in both the water and wetlands and woodland and forestry sectors (Defra, 2006c) and this should be developed further. There are also a number of generic issues surrounding protected sites, the wider countryside and the relationship between them, which should be considered across all EBS sectors.

Both terrestrial and marine protected sites will continue to be an important part of conservation strategy, although there are different specific issues. Marine protected areas are discussed in detail in Section 6.4.3b. The reasons for the importance of terrestrial protected sites are:

- They contain some of the most biodiverse communities in the UK. Not all species are threatened by climate change in their existing location and many still require protection from other causes of change.
- Protected sites have preserved low fertility soils, which are now rare in the wider countryside, particularly in the lowlands. Increasing fertility levels

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through agricultural modification (and atmospheric nitrogen deposition) has produced species-poor plant communities in which 'stress tolerant' (*sensu* Grime, 1976) species are excluded by relatively common, fast growing 'competitor' species (Smart *et al.*, 2003b; Haines-Young *et al.*, 2000). Even if the species composition of such a low nutrient community on a protected site changes with climate change, it is still likely to be diverse and contain species rare in the wider countryside.

- Protected sites include late successional communities and habitats which would take many years to re-establish following alternative land uses. For example Gibson and Brown (1992) estimated that to re-establish typical calcareous grassland on an ex-arable site would take a century or more. Ancient woodlands are associated with a distinctive flora, including ancient woodland indicator species, which are rarely seen in mature secondary woodlands.
- Sites which are managed specifically for conservation are most likely to be the ones in which direct measures for dealing with climate change can be developed and implemented. This is both because of the availability of resources and the presence of site managers specialised in conservation management.

Although protected sites will continue to be an important part of conservation strategies, there will need to be changes in the way they are managed and designated in some situations. The most acute issues are likely to be faced in the coastal zone. Rising sea level and consequent changes in patterns of erosion and deposition will cause some areas of high quality habitats to disappear. In many cases the only feasible response is to identify suitable sites in which new areas of valuable habitat may be allowed to establish, as part of managed retreat. Many existing citations for SSSIs are already 30-40 years old, and have not been updated, even if they were totally accurate at the time they were written. So, current targets may be inappropriate or inaccurate, and the gap between citation and reality will widen rapidly on many sites in the next 20 years. A flexible approach to designation is needed so that new sites can be and designation removed from sites if it is no longer appropriate.

Away from the coast, the issues will usually be less severe and as noted above, designated sites are likely to remain valuable even if they change. Nevertheless flexibility will still be important. In particular, what constitutes 'favourable condition' may need to be re-evaluated as features for which sites are designated become modified or lost as a result of factors beyond the control of managers. It will also be important to include new features of conservation importance (for example colonisation by a new species) in citations and targets for a site. This will require appropriate guidelines and regulation of the process of Common Standards Monitoring by conservation agencies. It will also require an understanding of climate change impacts by surveyors and site managers. Good ongoing channels of communication between specialists and practitioners will be critical.

The relationship between protected sites and the wider countryside around them is important. The resilience of designated sites may be improved by increasing their size and heterogeneity (6.3.3). Where a site is currently surrounded by land of low conservation value, it may be valuable to create new habitat around the edge, which

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will gradually develop in biodiversity interest, whilst at the same time functioning as a buffer between semi-natural habitat and the surrounding land. Increasing connectivity (6.3.2) with other areas of semi-natural habitat and increasing the biodiversity value of the agriculture matrix in which most designated sites are found, will also improve the resilience of those sites. Increased connectivity will also promote designated sites as a source of species for the surrounding countryside.

6.4.2 Agriculture

Agri-environment schemes are central to all aspects of biodiversity conservation in the Agriculture Sector of the EBS. There is scope to incorporate measures to tackle climate change impacts into the Environmental Stewardship schemes. For example where areas are seeded to create species rich communities, it could be recommended that seed mixes include those native (preferably local) species which are most likely to persist under future climates. The possibility of recommending inclusion of seed from a range of geographical locations, to increase genetic variation and potential for adaptation (Gregory *et al.*, 2006) should be investigated further. Over much of England it would also be advisable to ensure that native (local) species known to be resistant to drought (often those with deep roots) are included in the mixture (Morecroft *et al.*, 2004), given that most regional climate change scenarios indicate decreasing summer rainfall and more frequent extreme events.

Agri-environment schemes can potentially increase landscape connectivity and facilitate species dispersal. Uncertainty remains about the most effective means of achieving this and different types of organism will benefit from different approaches (see 6.3.2 and 6.3.3). Implementation of a range of measures which can be pursued on a no-regret (potentially win-win) basis could provide valuable evidence to guide future developments. Research and monitoring programmes are needed to test the effectiveness of different approaches and to develop prescriptions and guidelines in the light of experience.

Measures to improve the quality of the agricultural matrix include (Donald and Evans (2006) :

- hedgerow planting/restoration
- ditch management/restoration
- pond and scrape creation/restoration
- water level management
- grass strip/margin creation in arable fields
- uncropped margin creation in arable fields
- reduced pesticide/fertilizer inputs
- wild bird seed mix
- pollen/nectar mix
- winter stubbles
- summer fallows

Because dispersal needs to operate at a range of scales, including regional and national as well as the individual farm scale, mechanisms for planning and coordination will need to be developed to encourage longer range dispersal.

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Maintaining ecosystem function in the agricultural context is closely linked to conservation of biodiversity. Species-rich communities can benefit agriculture by increasing the availability of pollinators and natural predators of pests. The agricultural sector indirectly affects the functioning of other ecosystems, especially freshwater habitats and wetlands. Natural ecosystem function can be promoted by appropriate crop choice close to watercourses, the planting of trees and the management of riverine vegetation.

Agriculture provides a range of options for the mitigation of climate change, mainly focusing on reducing nitrous oxide and methane release, but also including carbon sequestration and the provision of alternative sources of fuel (Defra 2006c). There are other activities, such as wind energy generation, which are not directly concerned with agriculture but which impinge upon the agricultural sector when they are located on agricultural land.

Agriculture can adapt to climate change through changing the management of existing crops and livestock or by adoption of new species or varieties of crops and livestock. Some of these changes have the potential to impact negatively or positively on the biodiversity (Section 4.1), but much depends on specific circumstances and whether there are incentives to minimize threats and maximize opportunities for biodiversity. Similarly incentives for climate change mitigation measures should be targeted on those which provide biodiversity benefits or at least do not cause harm. Large scale adaptation or mitigation schemes should include an assessment of the impacts on biodiversity. An assessment of the potential impacts of future renewable energy policy on UK Biodiversity has recently been carried out (Hossell *et al.*, 2006).

6.4.3 Water and Wetlands

A landscape and catchment scale approach is central to reducing climate change impacts for the Waters and Wetlands EBS Sector. Many wetlands are inherently transient elements of the landscape that naturally form, evolve, metamorphose and disappear (often to become dry-land habitats), and this characteristic may become more pronounced under climate change. Management at the catchment scale implies acceptance that some sites may disappear whilst others establish in new, more suitable areas. This is implicit in landscape-scale wetland creation programmes (Mountford *et al.*, 2002, 2004).

For effective dispersal, functional connectivity must exist not only between rivers and their floodplains but also between upstream (source) and downstream (outlet) portions of a river. Flowing water acts as a vector for dispersal, so restoring connectivity between streams and rivers and their floodplains whilst reducing barriers across channels (or allowing their bypass) will facilitate species dispersal. River and wetland networks also favour dispersal of birds (including those moving between wintering, feeding and breeding grounds), mammals such as otter or water vole and insects that mate as adults on the wing, but complete their larval development in water, such as the southern damselfly.

A major impetus toward integrated management within the water and wetlands sector has been provided through the EU Water Framework Directive (WFD). The basic

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WFD vehicle of River Basin Management Plans requires outputs from assessment of both abstraction (i.e. overall water usage) and of flood risk and control. In the English situation such assessments will benefit from the use of Catchment Abstraction Management Strategies (CAMS) and Catchment Flood Management Plans (CFMP). As explicit in the EU Directive, these types of tool should provide the framework for a coherent management of water resources, both quantity and quality, for the full range of uses and needs.

Increasing habitat area is already an important aspect of wetland policy and management. Major wetland restoration schemes in Eastern England are amongst the most extensive in northwest Europe. At a local level, for example, the Cambridgeshire Fen BAP requires creation of a 200 ha wetland by 2010. More than twice this area was under active wetland creation by 2006, and the eventual target (for ca 2100) is ca 11,000 of wetland habitats. The viability of wet restoration schemes in southeast England needs to be carefully considered as summer evaporation is predicted to increase with climate change. Issues of water supply and storage need to be addressed from the outset of any plan to create wetland habitats; developing means whereby the increased winter precipitation can be stored and used to offset the reduced summer precipitation and increased evaporation. Plans for large scale wetland creation projects, the Great Fen Project and the Wicken Fen 100 year Vision, both in East Anglia, provide models for this approach.

In rivers and floodplains allowing for dynamic change and natural cycles of colonisation and succession can help to maintain biodiverse, semi-natural vegetation. These systems are also affected by the quantity and frequency of external inputs of nutrients and organic matter and the physical effects of water such as episodic erosion by rivers in flood (Loreau *et al.*, 2001). Catchment-scale approaches to landscape planning (Markham, 1996) can therefore promote conditions for healthy ecosystem functioning. This is also consistent with the Water Framework Directive and the need to minimise flood risks and ensure adequate water supplies. For rivers, alleviation and control of damaging floods can be achieved through floodplain restoration. Hydrosere succession (vegetation succession by which open water becomes dry land) and peat development can be promoted by management of drainage patterns, to create or restore mires and, in the same process, sequester carbon.

6.4.4 Woodland and Forestry

Within the EBS woodland and forestry sector there is a clear mechanism for promoting the planting of new woodlands under the English Woodland Grants Scheme and this will generally have a positive impact on biodiversity, so long as the trees are not planted on other important habitats. There is also scope to include direct management measures to reduce climate change impacts under this scheme. Mixed species stands will maximise the climatic tolerances of new woodlands. The emphasis should remain on native species for biodiversity conservation priorities, but with care taken to ensure that relatively drought-resistant species are included, especially in south east England. The sensitivity of beech woodlands to drought is well-recognised and their planting in suitable areas of the north and west, where it is not native, should be supported. At this stage however, beech should also continue to be a component of mixed planting in the south in areas where it is currently found.

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The planting of more drought-tolerant non-native provenances should be considered, particularly in new woodlands where production of timber rather than biodiversity is a major consideration. The planting of non-native tree species is controversial and is generally not recommended where biodiversity conservation is a priority, although it may be a valuable strategy for wood production.

There is a good opportunity to encourage the establishment of wet woodland in places that are subject to a high risk of flooding, and this habitat needs to be incorporated within plans for floodplain and large-scale wetland restoration. There are few other options for this land; wet woodland is a priority habitat which is rare in the UK and in some situations flood plain woodland can help reduce the risks of flooding in other areas downstream.

Forests are the natural vegetation of much of England they are usually self-sustaining without human intervention. This is likely to remain the case under all current climate change scenarios, although their species composition, of trees and other species, may change. Management intervention can direct ecosystem processes to optimise the balance between timber production, carbon sequestration, biodiversity and leisure opportunities. As noted in Section 4, pressure to increase wood production for climate change mitigation purposes is already increasing and an increased demand for wood products is also possible if world market conditions change.

Continuous cover forestry with natural regeneration, which takes advantage of natural forest dynamics, is an approach with many advantages in maintaining both wood production and biodiversity. Continuous cover maintains a shaded microclimate on the forest floor which is more likely to allow continuity of the present woodland flora and fauna.

The danger of windthrow, which can present problems for continuous cover forestry (Mason *et al.*, 1999), will have to be carefully evaluated and reviewed as the nature of climate change becomes clearer.

Within conservation sites a diversity of management strategies is likely to remain appropriate, including minimum intervention and maintenance of traditional systems such as coppicing. It may be possible to modify traditional systems to make them more resilient to climate change, by for example, retaining shading during coppicing using standard (full height) trees or leaving some stools un-coppiced. Care will be required to provide for those species, such as dormice, which require a more open canopy and continuum of seasonal food sources from the shrub and herb layers. There is also a case for allowing some woodlands to develop under a minimum intervention management regime, where natural processes predominate (Peterken, 2000, Mountford, 2000). This has some intrinsic benefits for some aspects of biodiversity, such as the build up of dead wood. Given the uncertainties of climate change a diversity of management strategies including minimum intervention, and a range of intensive conservation management (such as coppicing) and commercial management approaches is desirable. With appropriate monitoring this will allow the relative benefits for biodiversity to be assessed.

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Reconciling the needs of maintaining biodiversity and climate change mitigation (by use of wood fuels or long term carbon sequestration) is a critical issue in optimising sectoral responses to climate change. In general, promoting the use of suitable native species is likely to be better than non-native species for biodiversity. Conventional high forest is preferable to short-term rotation coppice in which there is little opportunity for woodland ground flora to establish. Short rotation forestry, an intermediate management strategy is preferable to short rotation coppice, if less beneficial than conventional woodland (Hardcastle, 2006). There are also promising opportunities to increase biodiversity (as well as to mitigate or adapt to the effects of climate change) by planting trees in agroforestry mixtures (section 4.1.2; section 4.3.2; Secretariat of the Convention on Biological Diversity 2003; 2006).

Strategies for climate change adaptation are starting to be translated into direct advice for owners and managers of woodland. For example a leaflet, 'Living with climate change and its effect on trees and woodland in the East of England', has been produced by the Forestry Commission, together with the Climate Change group of the East of England Sustainable Development Round Table (http://www.woodlandforlife.net/wfl-woodbank/documents/Climate_Change_PDF.pdf). Climate change is also beginning to be addressed in specific woodland management plans, for example that for Burnham Beeches (owned and managed by the City of London) for 2005-2010, considering the pollarding of beech (*Fagus sylvatica*) and other species states that 'in view of potential effects of climate change oak (*Quercus* sp.) should feature more prominently in number.' (http://www.cityoflondon.gov.uk/NR/rdonlyres/3560F960-F4D4-4F35-AE82-57B80D72816C/0/OS_BB_manageplan0510.pdf).

6.4.5 Towns and Cities

There is similar scope for direct management responses to climate change in urban areas as in rural ones. For example, where planting takes place, the use of a mixture of species and genotypes is to be encouraged, with a particular emphasis on native species which are likely to be tolerant of warmer conditions, summer droughts and, in some cases, winter floods. Management of existing habitats may require adjustment. Many urban grasslands, such as those in parks, are regularly cut and the timing of operations should be reviewed to ensure that they remain suitable under different climatic conditions, for example still allowing species to set seed.

In towns and cities important functional connections may be provided by gardens and public open spaces as well as by watercourses and woodlands (see below, for example, the case of regeneration at Queensborough and Rushenden, Kent; Piper *et al.*, 2006). Ecological networks are being promoted to reduce fragmentation, taking advantage of existing features. Urban biodiversity audits (e.g. London Biodiversity Partnership 2004) show that both public and private institutions (e.g. business parks, colleges, cemeteries) can contribute to encouraging this. Permeability of urban areas to dispersal of a wide range of species is potentially important not just for the biodiversity of urban areas themselves but also for longer range dispersal through them.

There is also potential for habitat creation in towns. This may be most easily achieved by including appropriate management of low diversity grassland in public

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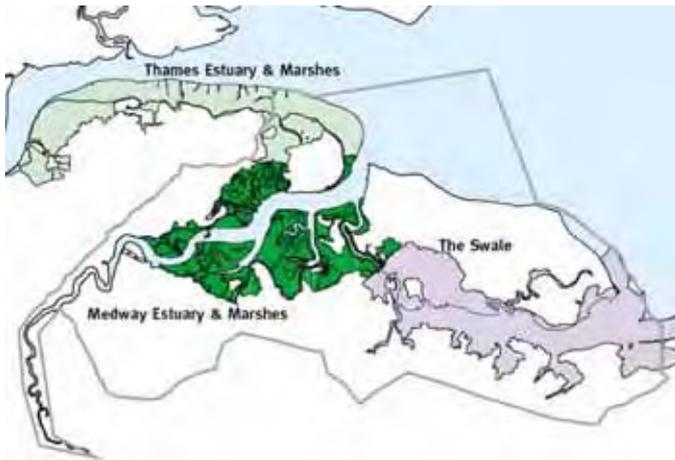
spaces and promoting biodiversity in private gardens. This is already a deliverable of the EBS towns, cities and development sector work programme for 2006-2010 (Defra 2006c). Innovative developments such as green roofs and walls have potential in the longer term. There are particularly good opportunities to engage the public in exploring habitat expansion possibilities in urban areas, such as ponds and, wildflower areas and enhancing buildings as habitats.

Management to minimise climate change impacts in the built environment will include the design of structures to benefit from and be resilient to changing conditions. Adaptations are likely to address water (flood and drainage) management and actions to reduce heat island build-up via: structure alignment, reduction of hard surfaces, increased area of green spaces and provision of water and shade (GLA, 2006). Developers should be encouraged to consider opportunities to enhance biodiversity when designing new developments - Supplementary Planning Guidance can help with this. Measures might include development of sustainable drainage systems, green roofs (LCCP 2006) and a “green infrastructure” of linked green spaces.

Case study: Queenborough and Rushenden, Kent (source: Piper, *et al.* (2006); Defra 2006)

The Queenborough and Rushenden regeneration area in Kent is located between three Thames Estuary Special Protection Areas (SPAs) containing habitats including saltmarsh, inter-tidal muds and freshwater grazing flats (Fig. 6.1a). Expected impacts of climate change at the site include scarce water resources, and flood risk from sea-level rise and storm surges, leading to impacts on biodiversity such as salt water intrusion, reduced groundwater flows into marshes, coastal squeeze and changes in the complex interaction of sediment erosion and accretion. The Master Plan (Fig. 6.1b) for the regeneration of the area, led by SEEDA highlights the wider landscape qualities of the area, especially the visual, water space and ecological assets of the Isle of Sheppey, and incorporates green and blue infrastructure (networks of open spaces and water) in the design. It aims to allow natural processes to continue: there would be minimal barriers to water and habitat movements, with a network of permeable ecological spaces, corridors and links; and a water management scheme maintaining the balance of evaporation and evapo-transpiration from the undeveloped marshes. Proposed designs include linking private and public green spaces to the existing habitats; incorporating creeks (without sluices) into the site; and phased multi-functional land-uses, such as conversion of public open space into meadow and ultimately into marshy flood-storage.

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Source: Swale Estuary Partnership



Source: Rummey Associates; Acknowledgments: SEEDA, LUC, CAG Consultants and Gardiner and Theobald

Figure 6.1 (a) Location and (b) Masterplan for the Queenborough and Rushenden Regeneration area

6.4.6 Coast and Seas

Sea-level rise is likely to represent the greatest climate-associated threat to intertidal and coastal habitats (Turner *et al.*, 1995). Even under present conditions only a small proportion of habitat lost is being replaced. In some areas the extent to which sea level rise is detrimental to coastal areas can largely be controlled through managed re-alignment (Sutherland, 2004). If sea defences are removed and landward movement of coastal habitats is facilitated, then the effects of sea-level rise on biodiversity will be minimal. If the landward movement of such habitats is hampered by coastal defence works or other obstacles such as roads and built developments or rising topography then there is likely to be a significant decline in

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many important intertidal and coastal habitats and their associated species (Sutherland, 2004).

There are numerous bodies responsible for coastal management in England, including Local and Regional Flood Defence committees, the Environment Agency, coastal district councils, land-owners and Defra. There are also several policy vehicles available for applying adaptation principles to coastal zone management. Foremost amongst these are Shoreline Management Plans: non-statutory plans developed by voluntary coastal-defence groups through consensus. Coastal ecosystems are complex and often poorly understood systems, which function at a variety of spatial-scales. Integrated coastal management will therefore need to be a continuous and adaptive process (Turner, 2001).

Despite the scientific and administrative challenges imposed by integrated coastal management, there are examples of good practice. In North Norfolk for example, the coast is much valued for its biodiversity, reflected in its designation as a SPA, SAC and SSSI. It is also recognised as an Area of Outstanding Natural Beauty. There are strong fishing, recreational and agricultural interests that conflict with these nature conservation interests. These problems are compounded because coastal defence works contribute to erosion elsewhere (Gill et al., 2001). The whole area is prone to inundation due in part to climate induced sea-level rise and in part due to unrelated land movements. The Snettisham to Sheringham Shoreline Management Plan has achieved consensus amongst stakeholders with widely dissimilar interests and empowered stakeholders such as local residents, normally on the “outside-track” of decision-making processes (O’Riordan and Ward, 1997). This was achieved by a repeated participatory process with two-way knowledge transfer, a model which could be replicated in other areas experiencing similar problems.

In the marine environment there has been much discussion over the need for Marine Protected Areas (MPAs) to be developed as an ecologically coherent network that provides for connectivity between sites (JNCC, 2004). This connectivity is important for a number of reasons, including the facilitation of species movements between sites via long-distance larval dispersal and migration of mobile organisms as adults (Bull and Laffoley, 2003). This helps to sustain populations over a species range although more research is required into issues of larval dispersal, metapopulation dynamics and MPA network design (JNCC, 2004). Although the nature of the marine environment means that there are generally fewer barriers to movement than there are on land, it is important that if a species is no longer able to persist in an area due to factors linked to climate change, that it is able to freely migrate to other areas. The ability to migrate / disperse from one area to another may become vital for a species to be able to survive (at least at local and regional scales) and it has been suggested that migration ‘corridors’ between areas could also become the focus of protection as MPAs (JNCC, 2004).

The issue of ‘stepping stones’ for marine species dispersal has received some attention, mainly focussed on the potential for seamounts to act as ‘stepping stones’ for trans-oceanic dispersal of oceanic species (e.g. Oliverio and Gofas, 2006) and whale falls to act as stepping stones for some hydrothermal vent species (e.g. Smith and Baco, 2003). In terms of direct intervention to promote dispersal as an adaptation mechanism, it is the placing into the marine environment of artificial

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structures such as sea defences in intertidal environments and renewable energy developments offshore that may provide the most ideal opportunities. For example, there is recent evidence that sea defences can act as 'stepping stones' for intertidal species (Mieszowska *et al.*, 2005) with species able to extend their range where previously their spread was restricted due to lack of suitable substrate. This has been observed in the English Channel where sea defences have reduced the distance between suitable habitats for rocky shore species (Mieszowska *et al.*, 2005). This may be seen as a positive benefit in enhancing dispersal but may also have implications for the spread of non-native species.

In the marine environment, there are a number of habitat Action Plans formulated under the UKBAP programme for the creation and restoration of habitats such as vegetated shingle (<http://www.ukbap.org.uk/ukplans.aspx?ID=29#5>) and coastal saltmarsh (<http://www.ukbap.org.uk/UKPlans.aspx?ID=33#5>). More research is required into the feasibility of creating some habitats such as seagrass beds (<http://www.ukbap.org.uk/UKPlans.aspx?ID=35#5>). The importance of research can be seen in the fact that despite the recognition of the urgent need for the creation of new saltmarsh habitat, there is still some disagreement on how this should be achieved. Hughes and Paramor (2004) and Paramor and Hughes (2004) have suggested that bioturbation by the ragworm *Nereis diversicolor* is a key factor in habitat loss and that, therefore, the restoration of saltmarsh habitat may involve factors other than managed realignment which is currently seen as the most appropriate measure in responding to coastal squeeze exacerbated by sea level rise. Others such as Morris *et al.* (2005), dispute these findings and suggest that adaptation to climate change impacts should still focus on managed realignment schemes. Understanding the causes of habitat loss, therefore, can be crucial if appropriate management measures for habitat creation and restoration are to be put in place (Wolters *et al.*, 2005).

6.5 Underpinning requirements

6.5.1 Monitoring

Monitoring is part of the wider evidence-base (Section 6.5.2), but it is dealt with separately here because of its importance. Monitoring, including what is sometimes termed surveillance, of change in populations and communities and the factors that control them, is critical for:

- Understanding the response of ecosystems, habitats and species to climate change and other pressures which may exacerbate this response
- Providing data for use in model development and testing, which will improve capacity to predict future change
- Assessing effectiveness of policy and management responses. Monitoring is integral to an adaptive management approach: it provides the key to learning from experience and responding to emerging trends.

It is important that monitoring is based on scientifically sound and statistically robust design, in order to maximise the chance of detecting trends and extreme events and separating them from natural variation, which is often considerable in environmental measurements. It is also important that monitoring data are available at the

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appropriate scales for the issues being addressed. These may range from site scale questions, such as ‘has a change in management made a difference to population size of a threatened species?’, through to regional and national scale ones, such as ‘are populations moving northwards?’.

Once changes have been detected, attributing trends to climate change is not straightforward in most cases, because of the wide range of other potential causes of change (Section 5) and the possibility of interactions between them. This makes it important to understand the mechanisms that cause change and also to monitor changes in the physical environment and land management in ways appropriate for interpreting the results of biodiversity monitoring.

Because of the long-term nature of climate change, it is essential that monitoring is established on a long-term basis. A long-term approach is also important because it can take a long time for trends or relationships between variables to become statistically significant, given the variability of most environmental data. Many ecological processes, such as succession also take decades to run their course and cyclical patterns including climatic ones (such as the North Atlantic Oscillation and El Niño) are not uncommon. The value of a biological dataset has been found to increase exponentially with its duration (Robinson *et al.*, 2005).

Many monitoring initiatives are in operation in the UK; Morecroft *et al.* (2005) provide short accounts of most of the major schemes for reference. Riley *et al.* (2003) reviewed existing and planned UK surveillance and monitoring schemes, to assess their adequacy for detecting climate-induced changes in biodiversity. They concluded that whilst there is a large amount of monitoring taking place, there was scope for much more integration and collation whilst gaps in coverage remained. Riley *et al.* (2003) suggested ‘three projects’ that could form the basis of a UK-wide climate change surveillance and monitoring framework:

- The collation of existing climate-related analyses and data into a single format – either a publication or on a website.
- Expanding the reporting structure to include collation and reporting of analyses from other regularly updated surveillance schemes which are not currently investigated from the perspective of climate change.
- Initiating new monitoring to plug taxonomic and habitat gaps in existing surveillance and monitoring programmes.

Whilst existing datasets can be exploited further, this will not provide all necessary information. A particularly important limitation of current monitoring is that there are relatively few sites where aspects of biodiversity are rigorously monitored alongside measurements of climate and other potential causes of change such as air pollution and land management. This is only done to any significant extent at Environmental Change Network (ECN) and ICP Forests Level II sites (Morecroft *et al.*, 2005). Ecological data for specific sites can be compared to nationally or regionally averaged data but some environmental factors such as ammonia deposition are subject to large local variations.

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The role of local soils and management history is also critical to establishing cause and effect in many cases. Similarly, monitoring of groundwater and nutrient input to waters and wetlands is necessary.

Attribution of biodiversity change to the correct mechanism is therefore stronger at more intensely monitored sites. Gaining this understanding is not just important for the development of the science, it is also important for informing policy and management decisions. In particular understanding the mechanisms causing change in biodiversity is essential for interpreting and validating the results of Common Standards Monitoring of designated sites (Bealey and Cox, 2004). What constitutes 'favourable condition' will need to be reviewed where changes beyond the site manager's control make former targets unattainable and new possibilities for promoting biodiversity need to be identified; it is clearly essential that this is done on the basis of the best available evidence.

Proposals to extend the Environmental Change Network, with a wider network of intermediate level monitoring sites (Morecroft *et al.*, 2006) would address this issue and should be taken forward. The future of ICP Level II plots, which monitor forest health in detail, is currently uncertain and opportunities to build on this work should be explored.

An important resource which may be increasingly useful for climate change impact assessment is the series of UK Countryside Surveys which have been carried out at 6-9 year intervals from 1978 onwards, with the latest in summer 2007. These provide detailed information on land use, landscape features and vegetation composition in a stratified random sample of 1 km squares throughout Britain (Haines-Young *et al.*, 2000). The long term, multivariate data set enables analysis of change in a range of countryside features, including habitats, condition of habitats and biodiversity between surveys.

As adaptation measures are implemented it will also be essential to monitor the outcome of different approaches to inform the adaptive management process. At present most monitoring work is focused on detecting impacts of climate change and further development will be needed to properly address this.

Some of the issues are different in marine and terrestrial environments but the principle of taking an ecosystem approach applies just as strongly to both. Gaining an understanding of changes in ocean currents and the impacts this has on biological communities is of high priority because of the drastic effects these can have on biological communities (Veit *et al.* 1997, McGowan *et al.* 1998). In marine areas, some oceanographic, physical and meteorological data are already collected under the auspices of the World Meteorological Organisation (WMO), International Oceanographic Commission (IOC) and International Council for the Exploration of the Sea (ICES). Long-term biological surveys, such as the Continuous Plankton Recorder Survey (<http://www.sahfos.org/>) are also ongoing.

The United Kingdom Marine Monitoring and Assessment Strategy (UKMMAS – <http://www.defra.gov.uk/environment/water/marine/uk/science/monitoring.htm>) is a major initiative to ensure that the UK can “*provide, and respond, within a changing climate, to, the evidence required for sustainable development within a clean,*

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healthy, safe, productive and biologically diverse marine ecosystem" (Defra 2006). This should be a major step forward in being able to assess current marine monitoring capabilities in the light of climate change and identify needs for the future. As for terrestrial monitoring, analysing climate effects in the marine environment and being able to disentangle these from other impacts can only be done using data from long-term time series and these are currently coordinated by the Marine Environmental Change Network (MECN) which was established in 2002. Despite their importance, many marine time series are poorly funded and the MECN is active in its support for the continuation and re-start of long-term research programmes.

Carrying out long-term research and monitoring in the marine environment is expensive (sometimes involving research vessels for example) but vital as outlined in a 2004 POST report (*"Long-term changes, such as those of climate change, can best be understood using long-term data sets, which can be costly and require long-term investment"*). Data from these time series have already been used to address climate issues and the recent Marine Climate Change Impacts Partnership Annual report Card Scheme utilised information from the network to provide information on climate impacts. The MECN also coordinates output from the Marine Biodiversity and Climate Change project (MarClim) project which ended in 2005. The MarClim project provided important data on climate change effects in the marine environment to policy makers and scientists (Laffoley *et al.*, 2005) and funds are being sought for its continuation.

An overview of how long-term marine observations are needed to support UK policy initiatives and provide the information necessary for understanding climate change effects can be found in Frost *et al.* (2005). Some long-term time series have now been incorporated in to Theme 10 (Sustained Observations) of the NERC Oceans 2025 strategic programme. A number of observatories will contribute to this programme and information on climate change from long-term monitoring and research will be disseminated via the MECN programme (the MECNs potential as a knowledge transfer mechanism has been acknowledged within that programme).

In the urban environment, priorities for monitoring include the proportion of soil covered with hard surface as well as the condition of watercourses and whether they provide appropriate conditions for wildlife throughout the year. The risk of failure of overwhelmed sewers, causing contamination of habitats and the availability and quality of green and semi-natural areas should be monitored. There are opportunities to encourage engagement and participation in monitoring activities from others, including site managers, land owners and the general public which could also contribute to the communication about impacts of climate change and adaptation measures.

6.5.2 Evidence base - Research

As with all policy and management decisions, it is important that adaptation to climate change is carried out on the basis of evidence. A key aim of the climate change adaptation workstream of the EBS is to establish "a robust and accessible evidence base to support adaptation to climate change" (Defra 2006c). In addition to scientific monitoring of change, it is important to improve understanding of the processes that drive change, and to develop the capacity to forecast future change.

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This requires the development of theory as well as manipulative experiments and modelling techniques. Socio-economic approaches are an important part of this in order to understand, for example, how land use may change in response to different scenarios and to quantify benefits for people of different strategies. A full discussion of the research needs for underpinning climate change adaptation policy is outside the scope of this report, but some of the main considerations are outlined here. A more detailed account of specific research priorities has been produced by The UK Biodiversity Research Advisory Group (Ferris, 2006).

The European Platform for Biodiversity Research Strategy (EPBRS) has recently identified knowledge gaps in relation to climate change at the European level (EPBRS, 2005). These knowledge gaps are found widely across Europe and the majority of them apply to England. Once knowledge gaps have been identified the next step is to try to fill them via further research, monitoring, literature reviews or knowledge transfer.

EPBRS (2005) recommended that immediate steps are taken by relevant funding bodies, institutions and researchers to address the following gaps in knowledge:

a) Quantifying climate change impacts on species, habitats and ecosystems.

- Improve our understanding of the effects of climate change on biodiversity as it acts through changes in the physical and chemical environments
- Quantify and forecast the responses of genotypes, species, habitats, ecosystems, landscapes and seascapes at all relevant spatial and temporal scales
- Improve understanding of the capacity of species and ecosystems to adapt to climate change
- Increase research efforts to develop methods to restore, maintain or improve the ecological functioning of protected areas, landscapes and seascapes for biodiversity conservation, and increase the coherence of Natura 2000 and other protected area networks
- Further develop methodologies for evaluating adaptation and conservation policies
- Improve understanding of the ways in which human factors influence the effectiveness of adaptation policies

b) Understanding interactions between biodiversity and sectoral adaptation

- Quantify the impacts on biodiversity of existing and proposed adaptation policies at relevant local, national and regional levels and temporal scales, through interdisciplinary and cross-sectoral research.
- Better understand and utilise the potential for biodiversity to contribute to successful adaptation to climate change across all sectors. This includes consideration of less intensive and more natural management of land and sea in providing opportunities for adaptation.
- Improve understanding of the impacts of climate change and biodiversity loss on human health and well-being.

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c) Providing adaptation policy advice

- Develop and test robust headline indicators of climate change impacts on biodiversity;
- Develop and implement means to incorporate learning from experience through systematic, iterative evidence-based, experimental and visionary processes to review legislation, policies and practices;
- Develop methodologies to reassess and define appropriate management units matching scales of ecological processes, in particular in the context of rapidly changing seas and coasts;
- Further develop principles, legislation, guidelines, and practical techniques for management of land and sea, sectoral adaptation, and spatial planning.

6.5.3 *Knowledge transfer and communication*

Knowledge transfer and communication are essential to the implementation of adaptation measures. This applies at a number of levels. Specialist knowledge needs to be made available to policy makers and managers in order to inform their decision making, and researchers and other specialists need to understand what information is required to inform those decisions. Scientific concepts need to be presented in a simple, straightforward way that is accessible to the wider public. The EBS climate change adaptation workstream has identified seven key messages that need to be communicated (Defra 2006c):

- Climate change is happening and will accelerate despite current mitigation efforts
- Climate change is a new and rapidly growing threat to biodiversity and poses an immediate and additional challenge to the target of halting biodiversity loss
- We need to revise our approaches to reflect and respond to increasingly dynamic species distributions and ecosystems, allowing for future revision of targets should evidence show that they have become unattainable due to climate change
- We need to start to adapt our policies and activities now in order to minimise the impacts on biodiversity
- There are many things we can do now on the basis of existing knowledge, but we need to continue to improve the evidence base so that we can be more effective
- Our understanding of impacts is still developing and we regularly need to take stock of new knowledge and be prepared to review and amend our approaches accordingly
- We need to learn to cope with an uncertain future and act with foresight and vision

The most appropriate means of communicating this message and the more technical information which is needed by managers and policy makers will differ according to context and a communication strategy is being developed by the EBS.

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Appendix 1 Indirect effects of climate change

As climate change takes place there will be changes in the working practices, development policies and land-use within each of the sectors. These changes will have both positive and negative implications for the biodiversity within that sector. This appendix identifies likely changes in working practices, development policies and land-use caused by climate change within each of the sectors and then assesses the impact of these changes on biodiversity.

This information is presented in table format. The potential changes caused by climate change are listed under three categories: changes in development policies, changes in land-use practices (unrelated to policy) and changes in working practices (unrelated to policy and land-use). The first column of the table shows the change in working practices, development policies or land-use. The second column indicates the likelihood of this change being made, ranked as high, medium or low. In most cases this is based on the expert judgement of the authors. The rest of the table is concerned with the impact of the change on biodiversity listing firstly the opportunities for biodiversity and secondly the threats. In many cases the impact on biodiversity of possible changes in working practices, development policies and land-use is unknown and information is based on the expert knowledge of the authors (EK in the reference column).

In the opportunities and threats columns, an indication of the magnitude of the impact on biodiversity, if the change occurs, is also noted. These are defined as: high (H) threat/opportunity, either the changes are expected to affect many areas or a significant number of protected areas or species of high conservation priority; medium (M) opportunity/threat, either the changes are likely to affect a significant number of areas or a few protected areas or a small number of species of high conservation priority; low (L) threat/opportunity, the changes are likely affect a few areas and are unlikely to have a significant impact on protected areas and species of high conservation priority. The final column lists references.

When using these tables the reader should consider the uncertainty relating to the likelihood of the changes in working practices, development policies and land-use being made combined with the uncertainty of how these changes will impact on biodiversity.

Appendix 1.1 – The indirect effects of climate change on the agricultural sector

Appendix 1.1 Agriculture

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Changes in development policies caused by climate change				
<i>Change in Food production policy</i>				
- Changes in crop types				
Change to more flower crops e.g. sunflowers, lupins, borage, evening primrose	High	Benefits caused by increased nectar source – more flower crops (H). Sunflowers likely to replace oil seed rape, buntings, sparrows and yellow hammers which feed on winter stubbles likely to benefit as sunflowers are sown in spring, unlike oilseed rape, which is sown in autumn (H).	Sunflowers likely to replace oilseed rape which England's declining population of linnets is increasingly reliant on for food (H).	Hossell <i>et al.</i> 1996 NFU, 2005
Increase in vineyards in Southern England	High		Expected to be detrimental as continental vine yards usually contain little wildlife	NFU, 2005
Traditional orchards could vanish in the south to be replaced with peach and other fruit crops currently grown further south	Medium	Impact depends on what landuse the orchards are replacing	Impact depends on what landuse the orchards are replacing	NFU, 2005
- Regional changes in range of crops:				
General increase in areas growing barley	High	Little impact if replacing a different sort of cereal crop	Little impact if replacing a different sort of cereal crop	NFU, 2005
Cereal production may move away from the South East of England and East Anglia to the west and north (as modelled by CLUAM)	Medium		Impact depends on what landuse the cereal production is replacing.	Parry <i>et al.</i> 1999 Hossell <i>et al.</i> 1996 NFU, 2005

Appendix 1.1 – The indirect effects of climate change on the agricultural sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Lowland leys moving onto lower yielding arable land (as modelled by CLUAM)	Medium	Maybe beneficial as greater variety of wildlife supported?		Hossell <i>et al.</i> 1996 Parry <i>et al.</i> 1999
Decline in sheep production in the lowlands (as modelled by CLUAM)	Medium	Beneficial if reduced grazing on previously overgrazed land.	Detrimental if grazing of semi-natural habitats completely stops and shrubs invade	Hossell <i>et al.</i> 1996 Parry <i>et al.</i> 1999
Increase in maize production, with more grown in the north	High		Maize is generally bad for farmland wildlife with few weeds, seeds and invertebrates compared to other crops (H). Decline in farmland birds e.g. skylark because maize crops are too tall and these birds prefer to nest in more open, shorter crops.	NFU, 2005 Burke 2003 Hossell <i>et al.</i> 1996 Cannell <i>et al.</i> 1999
- Changes in agricultural practice				
Warmer springs mean earlier sowing, more autumn planting of winter crops and opportunities for double cropping	High		If breeding birds or flowering season does not change then risk of crops being too tall and shading out arable flowers or being too tall for ground nesting birds. Double cropping could mean disturbance during bird breeding season. High impact on ground nesting birds such as lapwing and skylark (M). Autumn planting means decline in stubble and hence food for wintering birds like buntings and finches (M)	NFU, 2005
Earlier harvesting dates			If breeding birds or flowering season does not change then risk of destroying nesting birds, arable weeds	NFU, 2005 Aebischer <i>et al.</i> 2000

Appendix 1.1 – The indirect effects of climate change on the agricultural sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Intensification of rough pasture systems. Drought causes increase in weed species which are less nutritious for cattle, farmers likely to replace rough pastures with grass crops	High		Affect many birds that breed on rough pastures e.g. curlew and black grouse (H).	Pearce 2001
- Other				
Sowing of drought resistant varieties	Medium		Could encourage habitat loss. Risk of becoming invasive	NFU, 2005 Secretariat of the Convention on Biological Diversity 2006
Increase in local and sustainable agriculture	Medium	Increased diversity at the farm level	Loss of semi-natural habitats	
Changes in Energy policy				
Growing biofuels	High (especially on land not needed for urban or food production)	Willow coppice may provide some additional habitats in an heavy agricultural environment or on degraded land.	Willow coppice may destroy habitats of conservation importance if planted in semi-natural habitats. Increased nitrogen addition maybe necessary for biofuel production. Oil seed rape – same issues as if grown as agricultural crop. Elephant grass (miscanthus) is an ecological desert. Adverse impact on biodiversity if biofuels replace ecosystem with higher biodiversity.	Secretariat of the Convention on Biological Diversity 2003
Wind farms (an increase in wind farms on upland moorland/rough grazing)	High		Reduction in the abundance of many bird species	Stewart <i>et al.</i> 2004
Changes in Water policy				
Better water conservation in landscape	Medium (increasing as time goes on)	Good for biodiversity		EK

Appendix 1.1 – The indirect effects of climate change on the agricultural sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Irrigation – increased (irrigation likely to increase until such time as water scarcity causes licensing issues and a decrease in irrigation)	High		Causes low flow in rivers etc. May degrade water resources and aquatic ecosystems (H).	NFU, 2005 Secretariat of the Convention on Biological Diversity 2003; 2006
Irrigation – decreased (once demand for public water supply causes a decline in the water available for agriculture)	Medium	Generally good for biodiversity		NFU, 2005
<i>Changes in Carbon policy</i>				
Afforestation/reforestation	Medium	May provide increased habitats for woodland species if native trees planted. May increase biodiversity if planted on degraded land.	Will be detrimental if planted on land of higher conservation value e.g. many semi-natural habitats. If planted on agricultural land will cause loss of arable weeds. If plantations are of exotic species and/or monocultures then may be of limited benefit.	Secretariat of the Convention on Biological Diversity 2003
Short rotation plantations	Medium	Some short term benefits, but not as big as for longer term rotations.	The same negative impacts as for long term rotations above.	Secretariat of the Convention on Biological Diversity 2003
Agroforestry systems	Medium	Can greatly increase biodiversity, especially in landscapes dominated by annual crops or on lands that have been degraded. Can be used to functionally link forest fragments and other critical habitat as part of a broad landscape management strategy.		Secretariat of the Convention on Biological Diversity 2003

Appendix 1.1 – The indirect effects of climate change on the agricultural sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Conservation tillage includes methods such as chisel-plow, ridge-till, strip-till, mulch till and no-till all of which allow for the accumulation of soil organic carbon.		Provide beneficial conditions for soil fauna, but other impacts on biodiversity depend on the practice and the context in which they are applied.	Impacts on biodiversity depend on the practice and the context in which they are applied. Maybe detrimental if low tillage leads to increased herbicide application.	Secretariat of the Convention on Biological Diversity 2003; 2006
Erosion control practices; water conservation structures, vegetative strips, agroforestry shelterbelts, all reduce the displacement of soil organic carbon		May have some positive benefits for biodiversity but depends on which practices are used.		Secretariat of the Convention on Biological Diversity 2003
Improved management of grassland to enhance carbon storage		If native species are properly managed then carbon storage can be increased and biodiversity can benefit.	Risk of introduced exotic nitrogen fixers becoming invasive.	Secretariat of the Convention on Biological Diversity 2003
Avoid degradation of peatlands and mires to maintain them as a carbon sink.		Beneficial to biodiversity		Secretariat of the Convention on Biological Diversity 2003
<i>Changes in transport policy</i>				
Production of local food, decrease in food miles	Low, very sensitive to energy costs	Less road building, greater diversity of agricultural habitat	Pressure to increase production	EK
<i>Changes in Conservation policy</i>				
Habitats directive – forced to have greater landscape relevance	Medium, hard to enforce	Increases habitat heterogeneity		EK
Adaptive management (can't conserve what was there because of climate change)	Medium	Implies benefits	Maybe forced to take action without all the information being available.	EK
Changes in Site designation	High	Implies benefits		EK
Network of corridors	Medium	Benefits species able to move	Allows greater movement of aliens	EK

Appendix 1.1 – The indirect effects of climate change on the agricultural sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Change towards conservation of ecosystem services	Medium	Increases habitat diversity	Some habitats may be lost	Secretariat of the Convention on Biological Diversity 2003
Changes in land-use practices (unrelated to policy)				
Increased drainage to avoid flood risk	Medium		Detrimental to wildlife	NFU, 2005
Changes in grazing practices: warmer temperatures may mean that animals would not necessarily need to be removed from higher ground during winter and there may be opportunity to finish cows and sheep in upland areas.	Medium	Part of a general shift of agricultural habitats to higher elevation. Beneficial if reduced grazing intensity.	Risk of increased grazing pressure on upland areas, over grazing leading to loss of <i>Calluna</i> and increase in grass species	NFU, 2005 Secretariat of the Convention on Biological Diversity 2006
Livestock farming may move further north and west	Medium	Part of a general shift of habitats to higher latitudes		NFU, 2005
Changes in working practices (unrelated to policy and land-use)				
Uneconomic farms bought by “gentleman” farmers – for use of horses etc	High	Can increase habitat diversity and levels of weediness	Lack of knowledge of good farming techniques e.g. soil management	EK
Increase in tourism on heaths, calcareous grasslands etc with better weather – more walking etc	Medium	Increased income for better land management	Increased disturbance	EK
Increased accidental or deliberate summer fires on lowland heaths	High		Loss of nesting birds, reptiles and invertebrates	EK
Increased use of pesticides to control increased number of pests surviving due to mild winters.	Medium		Corn buntings and grey partridge have been shown to struggle to feed chicks from a reduced food source where pesticide applications are high (H)	Pearce 2001
Burning – change to burning dates for heather moorland	High (is already happening)	May benefit if burning dates adjusted correctly	May cause loss of habitat if burning either stopped or if burning gets out of control	EK
Lower fertiliser requirements (increased CO ₂ causes a increased yield so fertiliser requirements can decrease)	low	Benefit		NFU, 2005

Appendix 1.2 Water and wetlands

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Changes in development policies caused by climate change				
<i>Change in Flood defence policy</i>				
Raised flood-banks on floodplains	High	Some ability to regulate flooding of wetlands (L)	Separation of river from floodplain – reduced flooding of wetlands, reduced contribution of hydrochory (H)	ABI 2004, 2005 ODPM 2001, 2005b Ramsbottom <i>et al.</i> , 2005
Managed retreat	High	See coasts and sea section – also creation of brackish water wetlands (L)	Damage to freshwater habitats of biodiversity value in coastal zone (M)	Colston 2003
Greater demand for flood-storage areas	High	Flood-storage sites adaptable to restoration and conservation (M)	Management may be incompatible with other biodiversity goals (M)	Acreman <i>et al.</i> , (2003) Acreman <i>et al.</i> , (in press) Mountford <i>et al.</i> , 2002
Increased number of barrages and sluices on rivers	Medium	May allow for more flexible water-management (L)	Impacts on anadromous fish and hydrochory – require bypass/fish-ladders <i>etc</i> (H)	Haskoning 2006
Reduced channel maintenance	Medium	Create habitat diversity (M)	Few/none	Environment Agency 2005
<i>Changes in Conservation policy</i>				
Large-scale wetland restoration – to meet current BAP targets	High	Certain areas of UK may receive more (winter) rain, making restoration more feasible (L)	Increased (summer) evapo-transpiration makes bigger demands for winter storage and competition with other users for water-resources (H)	Mountford <i>et al.</i> , 2002, 2004 Sheail <i>et al.</i> , 1997
Increased demand for summer water in wetlands (e.g. reed beds and mires of south and east Britain)	High (but now very few sites)	None?	Inability to maintain wetness of peat leading to accelerated oxidation and wastage (H)	Benstead <i>et al.</i> , 1997 Poff <i>et al.</i> , 2002

Appendix 1.2 The indirect effects of climate change on the water and wetlands sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Increased development pressure on wetlands/ water-bodies outwith “sacrificial” areas (i.e.. outwith areas devoted to restoration and managed retreat)	Low	Mediate through links to agri-environment schemes (M)	Loss of spring-fed and relict or marginal wetlands (H)	Colston 20003
Protected areas policy – <i>Natura 2000</i> , SPA/SAC <i>etc.</i> Managing for multiple biodiversity purposes	Medium	Requirement to provide protection and to guarantee water supply (H)	Increased pressure on water-resources – some sites becoming non-viable as wetlands (H)	Commission of the European Communities (2006) Defra 2002a, 2006b, c
Water Framework Directive	High	Pressure to achieve high ecological quality of surface waters (and wetlands) – (H)	None? (Other than lack of funds/will to achieve compliance)	EU WFD (2000/60/EC) Maltby <i>et al.</i> , 2005
<i>Changes in Freshwater fisheries policy</i>				
Increased opportunities for invasive fish from warmer climates	Low?	Possible increase in range of native (southern) species (L)	Alien species may out-compete native stock under warm-water conditions. Would grass carp be able to breed? (M)	Davies <i>et al.</i> , 2004 Environment Agency 2006 Manchester and Bullock 2000
Changes in seasonal flow	High	None?	Summer low flows leading to de-oxygenation and prevention of fish mobility (H)	Arnell 19996 Arnell and Reynard 2000
Protection of salmonids	High	?	?	Environment Agency 2006
<i>Changes in Navigation policy</i>				
Expansion of amenity/recreational use	High	Public pressure to improve water quality (M)	Increased turbidity, pollution <i>etc</i> (H)	Martin 2005
Pressure for “low energy – high bulk” transport	Low	Removal of bulk loads from the roads, reduction of CO ₂ production (M)	Reduction of biodiversity value in canals and navigable rivers (M)	Haskoning 2006
<i>Changes in energy policy</i>				

Appendix 1.2 The indirect effects of climate change on the water and wetlands sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Siting of wind-farms on upland blanket-mires	High	Via reduction of C emissions	Increased erosion of blanket peats and associated vegetation	SNH (2001)
Expansion of Micro-hydro plants	Medium	Via reduction of C emissions	Interference to fish migration	SNH (2001), Curtis (1999)
Changes in land-use practices (unrelated to policy)				
Increased recreation in some major wetland areas – Broads, Lakes <i>etc</i>	Medium	Planned concentration of amenities at fewer “honeypots” (L)	Intense disturbance and localised pollution/eutrophication (M)	Martin 2005
Changes in disease risk				
Avian Influenza (H5N1); West Nile virus and other diseases of domestic (and wild) animals	High	None?	“Backlash” against wildlife	Buckley <i>et al.</i> , 2003
Resurgence of malaria (“Fen ague”)	Medium	None?	Pressure to drain final lowland wetlands	IPCC 2001a, c

Appendix 1.3 Woodland and forestry

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Changes in development policies caused by climate change				
<i>Change in Planting policy</i>				
Loss or partial loss of beech from southern England, planting of beech further north	High	Beech specialist species may be able to find new habitat in new woodland	Beech specialists may lose habitat in north but be unable to disperse to new habitats or fail to establish there.	Broadmeadow and Ray 2005 Broadmeadow 2002 Harrison <i>et al.</i> 2001 Broadmeadow <i>et al.</i> 2005 Wesche 2003
Increased planting of pendunculate oak at the expense of sessile oak	Medium			Broadmeadow and Ray 2005 Broadmeadow <i>et al.</i> 2005
Silver birch planted in preference to sycamore in south east	Low-medium?	Silver birch is native and sycamore is not. Birch also supports a higher number	Silver birch is also drought sensitive and may not survive long term in many sites.	Broadmeadow and Ray 2005 Broadmeadow 2002 Broadmeadow <i>et al.</i> 2005 Peterken and Mountford 1996 Peterken 2001
Commercially suitable range of Sitka spruce being restricted in England to southwest peninsula and the North West	Medium?	Unknown	Unknown	Broadmeadow and Ray 2005 Broadmeadow 2002
Corsican pine increases in suitability and growth rates and is planted more frequently	low (susceptible to red band needle blight)	Unknown	Unknown	Broadmeadow and Ray 2005 Broadmeadow, 2002
Douglas fir increases in suitability and growth rates and is planted more frequently	medium	Unknown	Unknown	Broadmeadow and Ray 2005 Broadmeadow, 2002
Planting of species or provenances originating from hotter, drier climates	High	Survival of native species if not native provenances	Loss of native genetic diversity	Broadmeadow and Ray 2005 Broadmeadow 2000

Appendix 1.3 The indirect effects of climate change on the woodland and forestry sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Planting mixtures of species and/or provenances as not all individuals will be affected by climate change to the same extent.	High	Mixture of species likely to be more beneficial to wildlife than monocultures. Woodland habitat more likely to persist under range of conditions.	None assuming mixture includes current British species and provenances	Broadmeadow and Ray 2005
Better connected woodlands at the landscape level	Medium	Benefit to woodland species	Loss of non woodland species?	Broadmeadow and Ray 2005
Reduced timber supply from overseas increases demand for UK production	Low at least in short term	Greater forest area planted increases habitat area	More intensive management reduces scope for conservation management	EK
<i>Changes in Water policy</i>				
Opportunities for the restoration of floodplain woodland are likely to increase	Medium	Good for biodiversity directly as wet woodland is a priority habitat and likely to support wider range of fauna and flora than e.g. agricultural land.		Broadmeadow 2002
Water framework directive – improved water quality	High	Good – clean water and catchment management plans		EK
Better catchment management planning in Southern England due to increased risk of water shortages and the water use of trees			Fresh water biota could be threatened by higher water temperatures and altered river flows if catchment management planning unsuccessful	Broadmeadow 2002 Broadmeadow 2000
<i>Changes in Carbon policy</i>				

Appendix 1.3 The indirect effects of climate change on the woodland and forestry sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Afforestation/reforestation	Medium	Will increase biodiversity compared to intensively managed agricultural land. Given sufficient time and appropriate management will provide increased habitats for woodland specialists, particularly if native trees are planted.	Will be detrimental if planted on land of higher conservation value e.g. many semi-natural habitats. If plantations are of exotic species and/or monocultures then benefits will be reduced	Secretariat of the Convention on Biological Diversity 2003
Increase in Short rotation coppice	High	Depends on species and management. Some short term benefits may occur, but not as big as for longer term rotations.	Will be detrimental if planted on land of higher conservation value e.g. many semi-natural habitats. NB rotations are too short for woodland flora and fauna to establish and herbicide use can be heavy.	Secretariat of the Convention on Biological Diversity 2003 Biomass Task force (2005)
Increase in Short Rotation Forestry	High	Some benefits compared to intensively managed agricultural land, e.g. providing habitat for birds, mammals and invertebrates. Scope for research and monitoring to identify best management practises	Will be detrimental if planted on land of higher conservation value e.g. many semi-natural habitats. Unlikely to develop typical woodland communities given regularity of disturbance	Hardcastle (2006)

Appendix 1.3 The indirect effects of climate change on the woodland and forestry sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Agroforestry systems	Medium	Can greatly increase biodiversity, especially in landscapes dominated by annual crops or on lands that have been degraded. Can be used to functionally link forest fragments and other critical habitat as part of a broad landscape management strategy.	Loss of arable habitats	Secretariat of the Convention on Biological Diversity 2003
Intensification of forest management to increase availability of biomass fuels	High for some woodlands	More frequent opening of forest canopy during thinning may be advantageous for ground flora and fauna it supports.	Decrease in dead wood reduces habitat for saprophytes	Biomass task Force (2005)
Carbon reserve management (minimal intervention)	medium	Benefits to biodiversity particularly if native species planted		Broadmeadow and Matthews 2003
Carbon substitution management (cyclical changes in carbon density in the forest, woody biomass is harvested as good quality stemwood for use in product displacement and renewable woodfuel.		Unknown	Unknown	Broadmeadow and Matthews 2003
Selective intervention carbon management (similar to carbon reserve management but in addition there is low-level harvesting of certain trees to clearly defined specifications in order to supply high-value niche applications.		Unknown	Unknown	Broadmeadow and Matthews 2003
<i>Changes in Conservation policy</i>				
Habitats directive – forced to have greater landscape relevance		May be beneficial		EK

Appendix 1.3 The indirect effects of climate change on the woodland and forestry sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Adaptive management (can't conserve what was there because of climate change)	Medium	To increase chances of survival of species and habitats at national scale	Inappropriate intervention may cause loss of existing biodiversity	EK
Changes in Site designation	High	Should be beneficial		EK
Network of corridors	Medium	Benefits species able to move	Allows greater movement of aliens	EK
Change towards conservation of ecosystem services				Secretariat of the Convention on Biological Diversity 2003
Changes in working practices (unrelated to policy and land-use)				
Increased numbers of pests and pathogens			Death of native species	Broadmeadow and Ray 2005 Broadmeadow 2000 Broadmeadow 2004 Broadmeadow 2002
Grey squirrel control (grey squirrel population likely to increase due to reduced winter mortality and increased seed availability)			Red squirrels likely to decline if grey squirrels increase	Broadmeadow and Ray 2005 Broadmeadow 2000 Boadmeadow 2002
Deer control (populations likely to increase because of reduced winter mortality and advanced growth of ground vegetation increases forage availability)		If deer control successful increased regeneration will occur and ground flora recover	If deer control not carried out tree regeneration will decline. Ground vegetation will be reduced and tend towards grazing resistant types of plants, particularly grasses	Broadmeadow and Ray 2005 Broadmeadow 2000 Broadmeadow 2002
Increased fire control (risk of fires increases with increased frequency and severity of summer droughts and increased fuel availability)		If fire control successful better maintenance of woodland	If fire control unsuccessful loss of woodland structure	Broadmeadow and Ray 2005 Broadmeadow 2004

Appendix 1.4 Towns, cities and development

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Changes in development policies caused by climate change				
Strategic Planning for biodiversity	High	Strategic scale planning in areas of high landscape value, e.g. for ecological networks, resilient ecosystems (woodlands, chalk downlands and heathlands). (H)	Failure to achieve strategic planning - exacerbating fragmentation	SEERA 2005 RSPB 2006
Local planning for biodiversity; LDFs	Moderate	Provide for green corridors, stepping stones, buffer zones and ecological networks (H)		Piper <i>et al.</i> 2006
Safeguarding potential biodiversity sites	Moderate	Possible retention of corridors/patches, etc. with potential to permit species movement (M)	Failure to achieve adequate biodiversity networks (M)	Piper <i>et al.</i> 2006
Compensatory measures	Moderate	Possible mitigation of losses (L)	Failure to provide adequate compensation (M)	ATECMA, unpublished study for CEC
Water supply policy (i.e. to take account of the possible shortfall in water supplies as a result of climate change)	High		Responses to future shortfalls might cause further demands on scarce resources (such as abstraction from water-courses), with attendant impacts on aquatic ecology. Longer-term provision of infrastructure such as storage or water-transfer is likely to have direct and indirect impacts on habitats and species. (H)	Downing <i>et al.</i> , 2003 Environment Agency 2005

Appendix 1.4 The indirect effects of climate change on the towns, cities and development sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
<p>Policies to meet demand for water (i.e. demand associated with new housing development)</p>	<p>Moderate to high Current plans for more housing, and estimates of continued household formation are likely to lead to increased demand for water in the absence of major behavioural changes.</p>		<p>Responses to future shortfalls might cause further demands on scarce resources (such as abstraction from water-courses), with attendant impacts on aquatic ecology. Longer-term provision of infrastructure such as storage or water-transfer are likely to have direct and indirect impacts on habitats and species. (H)</p>	<p>The CCDeW report (Downing <i>et al.</i>, 2003) concluded that industrial/commercial demand might increase by 3.6-6.1% by 2050s, agricultural demand for irrigation by 20% by 2020s and by 30% by 2050s, and domestic demand by 2.7-3.7% by 2050s. These figures may be underestimates - (HoC EFRA, 2004)</p>
<p>Water efficiency policy</p>	<p>Moderate</p>	<p>If reductions in demand are achieved this would protect wetlands, groundwater levels and river levels. (M)</p>		<p>The planning system has the potential to require higher standards of water-efficiency and water re-use systems such as grey-water recycling, but this will only apply to new development, which represents c.1% pa of residential properties and c.2% pa of commercial properties IPPR, 2005</p>
<p>Sustainable Urban Drainage Systems (SuDS)</p>	<p>Moderate</p>	<p>A major opportunity for biodiversity and the implications for biodiversity should be beneficial. Policies requiring SuDS are being incorporated into local development plans. (H)</p>		<p>Environment Agency 2003 ODPM 2001 ODPM 2005c</p>

Appendix 1.4 The indirect effects of climate change on the towns, cities and development sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Avoidance of flood-plains and minimisation of flood risk	Moderate	Protection of floodplains and hence protection of inherent biodiversity. (M)	Direct impacts of flooding for some species (e.g. ground nesting birds) at water-logged sites May divert development to brownfield sites currently important to wildlife. (M)	OST Future Flooding 2004 Environment Agency 2005 ABI 2004 and 2005 Howe and White 2002 HoC EFRA Select Committee 2004 HoC Environmental Audit Select Committee 2005 IPPR 2005
Managed realignment	High	Development of new saltmarsh (L) (replacement at best)	Loss of freshwater wetlands (M) Some loss of salt marsh (M)	Cobboid and Santema 2001 Hampshire County Council 2003 RSPB 2001 National Trust 2005
Policies to promote urban cooling	Moderate	Open space and shade tree planting providing space for biodiversity, either in new opens spaces, new developments or by “greening” of existing open spaces or developments. (M)		London Assembly 2005 Hacker <i>et al.</i> , 2005 EPSRC and UKCIP 2005 EcoHomes and StudioEngleback 2003
Urban intensification as a result of climate change to reduce transport-generated CO2 , and to conserve upstream floodplains	High to moderate (location dependent)		Urban densities have been increasing as a result of explicit government policy of an increase in urban densities through redevelopment and infill development This has potentially significant implications for the loss of biodiversity in “green” lower density suburbs (H)	ODPM 2005a Gwilliam 1999 UK BAP Action Plan: urban habitats: parks, gardens and brownfield Austin <i>et al.</i> 2003
Safeguarding transport networks	Low	Potential for corridors/networks (with appropriate design) (M)	Safeguarded routes for re-aligned major networks, e.g. Devon coast (L)	SWCCIP 2004 SECCP 2004 ODPM 2004a
Changes in working practices (unrelated to policy and land use)				

Appendix 1.4 The indirect effects of climate change on the towns, cities and development sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
SEA and sustainability appraisal of plans and policies	High	Requirement for incorporation of mitigation/compensation measures where biodiversity sites are affected by development (H)	Any tendency to divert development to brownfield land with high biodiversity value. (M)	ODPM 2005b
Planning gain obligation		Potential for enhancing/creating sites with nature conservation value (M)		

Appendix 1.5 Coasts and Seas

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Changes in development policies caused by climate change				
<i>Change in Flood defence policy</i>				
Increased protection of cliffs, beaches and other areas	High	Control of influx of saline water into brackish lagoons and other habitats (H)	Hypersaline conditions in brackish lagoons in summer, habitat loss due to flood defence works and increased erosion of other unprotected areas (H). Coastal squeeze (M).	Joyce <i>et al.</i> 2005 Stewart 2001 UKBAP 1994, 2005
Managed retreat	High	Development of new saltmarsh and mudflats (M)	Loss of saltmarsh, coastal grazing marsh and intertidal mudflats (H). Loss of habitats further inland (L).	Crooks 2004 Hughes 2004
Increased number of barrages on rivers and estuaries	Medium	Control of waterflow to benefit biodiversity	Prevention of migration of marine fish species that spawn up river and of freshwater fish that spawn at sea (H). Loss of feeding habitat for waterbirds (M).	Burton <i>et al.</i> 2001 UKBAP 1994 EK
<i>Changes in Conservation policy</i>				
Site designation/protection	High	Designation of new SPAs etc in the North and East (M)	Network of protected areas may not be sufficiently connected to accommodate climate-mediated movements (M). Increased pressure to de-notify or develop sites with decreased biodiversity interest (L).	Austin and Rehfisch 2005 Maclean <i>et al.</i> 2005 Maclean <i>et al.</i> in review Rehfisch <i>et al.</i> 2004
Habitat protection	Medium	Greater emphasis on conserving habitats threatened by climate change (e.g. saltmarsh)	Climate change induced modification to habitats such that existing policies no longer effective (L)	Boere and Taylor 2004 Sutherland 2004

Appendix 1.5 The indirect effects of climate change on the coasts and seas sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Species protection		(L)		
	Medium	Possibility of placing more emphasis on species protection at an international level, thus accounting for range shifts (L)	Due to higher species richness at lower latitudes, and general northward shift in ranges, general perception that status of birds in England is improving, when at an international level this is not the case (L)	Boere and Taylor 2004 Maclean <i>et al.</i> in review, Sutherland 2004 EK
<i>Changes in Fisheries policy</i>				
Setting of fisheries quotas	High	Reduced pressure on species detrimentally affected by climate change, northward shift may reduce pressure on some commercial species (H)	Additional pressure on species already adversely affected by climate change, increased pressure on southern species as they move north (M). Impact on other species within the food chain (M).	Pitcher 2005 Sutherland 2004
<i>Changes in Water policy</i>				
Changes in water abstraction	High	Tougher regulations may favour breeding waders etc. on coastal grazing marsh (M)	Increased water-abstraction due to agricultural demands may lead to lowering of water-tables, and detrimental effects on breeding waterbirds etc. (L). Increased salination of freshwater habitats (M).	Smart and Gill 2003 EK
Changes in land-use practices (unrelated to policy)				
Increased creation of recreation facilities in coastal areas	Medium	Concentration of recreational activities at fewer locations (L)	Habitat loss. Increased disturbance at coastal areas (M)	Wall 1998 EK
Habitat conversion of semi-natural habitats to agricultural land as existing land is inundated or eroded	Low	Increased opportunity for entry into agri-environment schemes (M)	Conversion of important wildlife habitats into intensive agricultural land (L)	Sutherland 2004 EK

Appendix 1.5 The indirect effects of climate change on the coasts and seas sector

Change caused by climate change	Likelihood of changes made	Opportunities for biodiversity	Threats to biodiversity	References
Changes in working practices (unrelated to policy and land-use)				
Increased number of visitors to coastal areas	Medium	Concentration of visitors to areas unimportant for biodiversity	Increased disturbance to coastal areas. Increased erosion of sand-dunes (M)	Martin 2005 Wall 1998