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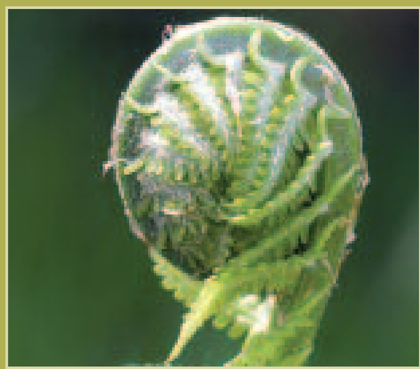
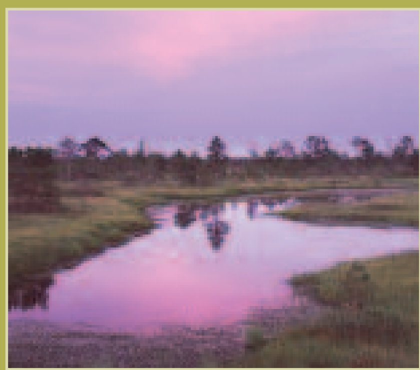
Climate change and biodiversity in Europe: a review of impacts, policy responses, gaps in knowledge and barriers to the exchange of information between scientists and policy makers





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Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

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Climate change and biodiversity in Europe: a review of impacts, policy responses, gaps in knowledge and barriers to the exchange of information between scientists and policy makers

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Executive Summary

The threat of climate change to Europe's biodiversity

Anthropogenic climate change is already impacting upon biodiversity. Climate change is driven predominantly by the release of greenhouse gases into the atmosphere as a consequence of fossil fuel combustion (but also from agricultural and industrial processes). It is manifest through changes in temperatures, precipitation patterns, global mean sea levels and the activities of ocean circulatory systems. Not only will there be changes in the average climatic conditions, modelling scenarios also indicate an increased frequency of extreme climatic events. In Europe there is spatial variation in the predicted changes in climatic conditions, with the greatest levels of warming predicted for Mediterranean and north-eastern areas, increased precipitation in northern areas and decreased precipitation in southern areas.

The impacts of climate change on Europe's biodiversity

Climate change has been proposed as one of the major threats to the global biodiversity resource. Information on the response of European biodiversity comes from two main sources: observed responses of biodiversity to recent climate change and modelled scenarios of future biodiversity responses.

Observed climate change impacts

In terrestrial ecosystems there has been a trend toward earlier springs, including earlier flowering and bud-burst dates for plants, and earlier periods of activity (appearance, breeding, migration) for many animal species. Species' ranges have moved, with northerly shifts (and upward shifts in mountain systems) in the ranges of bird, butterfly and plant species, and trends in local flora that show a reduction in "cold" species and an increase in "warm" species. Range shifting may also be altering species' behaviour and morphology – species may be evolving in order to track their preferred climate. However, limitations exist on the ability of species to track optimum climatic conditions (e.g. habitat fragmentation).

In coastal and marine ecosystems, seasonal events such as the onset of growth and reproduction are also occurring earlier during the year, and there is a general northerly movement of species ranges (although there is spatial variation in the changes in these distribution patterns – some ocean areas have undergone cooling, and the flow of currents around coastlines may not mean that all species migrations are northerly). Although some areas have seen an increase in productivity due to warmer conditions and increased phytoplankton production, areas that are already warm have seen reduced productivity in response to further warming. In marine systems, as in terrestrial systems, there are barriers to the movement of species.

Predicted climate change impacts

Information on the future impacts of climate change comes from manipulative experimental studies and climate change impacts modelling. Scenarios of climate change impacts on biodiversity are produced by coupling species distribution models to scenarios of future climate. Some relatively consistent trends emerge from these scenarios and experimental studies.

A number of processes, in particular changes in the growing season and timing of biological events, as well as differences in the ability of species to shift ranges, will lead to changes in the composition of terrestrial communities. Communities will not move as unaltered units. Changes in climatic conditions will alter the productivity of ecosystems, and this will vary spatially across Europe, with increased productivity in northern areas such as Scandinavia and northern Russia (and a potential shift from tundra to shrub/tree dominated ecosystems), and decreased productivity, as well as increased risk of fire events in Mediterranean areas. Changes in climatic variability may lead to the loss of rare species, or those at the margins of their ranges. Typical arctic and alpine vegetation and species will suffer from reduced coverage.

In freshwater ecosystems changes in the level and timing of flow events, in response to altered precipitation patterns, will alter the suitability of some sites for particular species. Increased temperatures will make some habitats less suitable, both because of the changes in water temperature per se as well as changes in oxygen availability, and within lakes species might retreat to deeper, cooler waters. An important component of the response of wetland systems is the potential for drying of some areas, especially those with considerable peat deposits, leading to CO_2 release.

In marine ecosystems increasing temperatures will likely continue to alter the timing of the growing season and plankton blooms, with the potential for trophic mismatch in marine food chains. As in terrestrial systems there is likely to be a general trend toward a northerly shift in species' ranges, and different species will have different capacities to move ranges. Shoreline habitats will be affected by increased storminess and windiness.

Uncertainties

All of the above scenarios involve uncertainties. Key sources of uncertainty include:

- The level of detail at which modelling can be conducted.
- The different abilities of species to respond to climate change.
- The interactive effect of climate change with other drivers of biodiversity change.
- Non-linearity of responses (e.g. the occurrence of zero-analogue climatic conditions).

Policy responses to the impacts of climate change on biodiversity

Current policy

Climate change policy has been shaped by the 1992 UNFCCC (United Nations Framework Convention on Climate Change), which was aided by the first report of the IPCC (Intergovernmental Panel on Climate Change), and its proposed actions for reducing greenhouse gas emissions were strengthened by the 1997 Kyoto protocol. A number of key conventions and directives have determined the development of biodiversity policy across Europe, in particular the 1971 Ramsar Convention, the 1979 Bonn and Bern Conventions and EC Birds Directive, and the 1992 EC Habitats Directive. A major recent development is the Convention on Biological Diversity (CBD), in response to which the European Commission produced its 1998 Biodiversity Strategy, detailing how to link the CBD to particular activities within the EC. The 2001 Gothenburg Council of EU Heads of State committed to "halt the decline of biodiversity by 2010" and adopted the EU Sustainable Development Strategy (EUSDS), which was extended to a Pan-European region by the 2003 Kyiv Resolution, whose commitments are supported by PEBLDS, the Pan-European Landscape and Diversity Strategy. However, despite these substantial commitments recent reviews and commentaries have highlighted a continued decline in the Europe's biodiversity resource, and the need for a renewed commitment to stopping this trend.

Future policy

Policy to deal with the impacts of climate change can be categorised into mitigation (attempting to limit further changes in global climate) and adaptation (optimising the outcome of those changes that will inevitably occur). With respect to biodiversity conservation, adaptation strategies would aim to conserve biodiversity despite the impacts of climate change. There is now widespread recognition of the need to develop adaptation strategies for biodiversity conservation. Existing biodiversity policy rarely explicitly considers adaptation to climate change impacts, but changes to existing policies may not be necessary given their generic commitment to maintaining the biodiversity resource in a "favourable" state.

The implementation of policy, and in particular EPI (Environmental Policy Integration – the consideration of biodiversity impacts in the development of policy in all sectors), is also an area that needs addressing to promote biodiversity conservation during climate change – maximising biodiversity conservation will depend upon effective EPI, as well as clarification of the concept of sustainable development to promote the implementation of the EUSDS. Major barriers to the implementation of EPI, and the development of new policy, are the perceived cost. However, careful design of sectoral adaptation strategies and a realisation of the financial value of ecosystem services (maintained by biodiversity) would promote integration of biodiversity conservation. Importantly, because of a lack of EPI, sectoral adaptation strategies are already being implemented without regard to their impacts on biodiversity.

Gaps in knowledge, research priorities and barriers to knowledge transfer

Climate change impacts on biodiversity

Despite the fact that a substantial amount of scientific information already exists relating to climate change and climate change impacts on biodiversity, access to this information is often problematic, and would be aided by the creation of digitised bibliographic information (i.e. detailing available scientific literature and information) in searchable databases. Further research is needed to:

a) Understand the impact of different aspects of climate change on biodiversity, including examination of a range of climatic drivers, and extreme events;

b) Understand climate change impacts on poorly studied but potentially crucial systems for providing ecosystem services (e.g. soil communities);

c) Predict responses of biodiversity at finer scales, and to provide fine-scale scenarios for biodiversity change with high levels of certainty, taking into account the role of processes such as habitat fragmentation, biotic interactions, and species-specific variation in migratory and evolutionary capacity;

d) Understand interactions between the processes regulating biodiversity;

e) Develop modelling approaches that incorporate the impacts of multiple drivers of biodiversity change;

f) Develop long term monitoring, including the design of new monitoring frameworks, and setting adequate baselines;

g) Understand the impacts of climate change on biodiversity and human health (e.g. consequences to ecosystem services, distribution of pest and disease vectors etc).

Development of adaptation strategies for biodiversity conservation

The integration of biodiversity conservation into adaptation and mitigation strategy development is currently poor, with a lack of genuine cross-sectoral policy development to promote biodiversity conservation. Priority activities in the development of adaptation strategies for biodiversity conservation will therefore need to start with the identification and evaluation of existing biodiversity legislation to assess whether or not these encompass the activities needed to adapt to climate change impacts. Protected areas will be essential components of adaptation strategies. However, little is known on how climate change might impact on existing protected areas and how these impacts might be mitigated. Research in both protected and non-protected areas is essential if we are to create resilient ecosystems and permeable landscapes. Vulnerable ecosystems in particular need further research to define thresholds, set mitigation targets and guide landscape-scale planning. Research should feed directly into spatial development plans that incorporate the likely impacts of climate change on biodiversity and integrate ecological knowledge into the planning process at different scales. All implementation of adaptation strategies needs to be associated with monitoring and ongoing refinement.

Most adaptation strategies will amount to little unless they are linked directly with sectoral responses. In this respect, developing a broad scale multi-sectoral assessment of adaptation and mitigation strategies and an effective institutional framework to promote biodiversity conservation will be essential. The framework will require the development of methodologies to determine the economic value of the biodiversity resource and the development of scenarios of future sectoral development e.g. agricultural, forestry, water resource and energy sector development, under climate change (including understanding the impact of increased climate variability).

Interdisciplinary research in climate change studies is a key priority cutting across all the above research priorities. Scientists will have to overcome the challenges of interdisciplinary research (including the integration of different kinds of knowledge, including local knowledge) by developing methods to quantify uncertainty and assess risks, and communicating results directly to governments and indirectly to other policy-influencing actors through interactive networks.

1. INTRODUCTION

1.1. Context and aims of this report

Climate change is now widely recognised as one of the major drivers of global biodiversity change and loss. It is therefore necessary to consider what measures might be taken in terms of the development of policy and research strategies, in order to minimise these impacts and conserve biodiversity. Considerable discussion is currently underway within Europe on these issues. Such discussions need to bring together information on the impacts of climate change on biodiversity in Europe (both observed and predicted impacts) and the existing policy framework for biodiversity conservation, and to identify gaps in knowledge or barriers to knowledge transfer that prevent the implementation of existing policies or development of new policies.

As part of this process Defra organised a meeting in October 2005 of the European Platform for Biodiversity Research Strategy (EPBRS) in Aviemore, Scotland, under the UK Presidency of the European Union. The meeting was entitled "Climate Change and Biodiversity Conservation: knowledge needed to support development of integrated adaptation strategies". The meeting reviewed the scientific evidence and provided recommendations in three areas:

(i) Current knowledge about the impacts of climate change on biodiversity and the policy responses required

(ii) The most important aspects we need to know about to develop adaptation strategies; and

(iii) How to ensure the flow of knowledge from research into policy development.

Recommendations from the EPBRS meeting were then fed to a meeting of the EU Nature Directors (5-7th October, Aviemore, Scotland). For outputs from these meetings see Appendices 2 and 3 respectively.

This report was produced to aid the work of the EPBRS at the Aviemore workshop. Its aim was to review the impacts of climate change on biodiversity in Europe, the current, planned and proposed policy responses to those impacts, and the known knowledge gaps and barriers to knowledge transfer that prevent the development of policy responses.

1.2 Approach

A draft report was produced by the project team based upon a literature review of both research and policy documents. Although detailed reviews of current and predicted impacts of climate change on biodiversity are available elsewhere (e.g. IPCC 2002, CBD 2003), this paper updated these reviews by including information from recent project reports and meeting outputs (e.g. RHS 2005, EEAC 2005).

The draft version of the paper (sections 1 – 4) was posted for comment during an electronic conference on 'Climate Change and Biodiversity Conservation: Knowledge needed to support development of integrated adaptation strategies', 29 August – 16 September 2005. Information from the keynote papers and discussion from this conference were included during revision of the report, and in particular in the production of section 5, prior to submission to the EPBRS meeting. In addition five background papers were produced to support working groups at the EPBRS meeting (Appendix 1).

Following the EPBRS and Nature Directors' meetings, as well as a process of peer review, additional information has been included in this document including information from the output of both of these meetings (Appendices 2 and 3), as well as from a background paper produced by the IUCN for the Nature Director's meeting (IUCN 2005).

2. CLIMATE CHANGE

2.1 Observed changes in climate

The Earth's climate has experienced an average warming of approximately 0.6-0.7°C during the past 100 years, with an increased rate of warming particularly since the mid 1970s and with the 1990s being the warmest decade in the observational record (Houghton et al. 2001, EEA 2004a). Although the Earth's climate has always oscillated between warm and cold periods, sometimes rapidly (Houghton et al. 2001) there is strong evidence that the majority of the recent rapid temperature increase is a consequence of anthropogenic climate forcing due to increased release of greenhouse gases into the atmosphere (Houghton et al. 2001). The main greenhouse gas is CO_2 (carbon dioxide), the increased atmospheric concentration of which results from the combustion of fossil fuels, cement production and land use change. Other important anthropogenic greenhouse gases include CH_4 (methane) from agriculture, N_2O (nitrous oxide) from agriculture and industry, and halogenated gases and ozone from industrial and domestic sources (EEA 2004a). In addition to enhanced temperatures, other climate changes that are likely to be the consequence of anthropogenic activity include changes in precipitation patterns and the frequency and severity of extreme climatic events (Houghton et al. 2001). These changes in climatic conditions are likely to have led to reductions in snow and ice cover, changes in the activity of ocean circulatory systems such as the El Niño Southern Oscillation and an observed general rise in the temperature of the oceans. Thermal expansion of the oceans due to warming is likely to be the cause of an observed rise in sea level (Houghton et al. 2001).

2.2 Projected changes in climate

Because the future development of human populations, their associated energy consumption and technologies and hence the future outputs of greenhouse gasses are uncertain, and because of an incomplete understanding of climate processes it is not possible to "know" the extent of future climate change (EEA 2004a). However, future climate projections have been made using increasingly realistic Global Circulation Models (GCMs) and based upon emission scenarios that include potential responses of society to the threat of climate change. The climate projections from these models include (Houghton et al. 2001):

- A warming of the global average surface temperature of between 1.4 and 5.8°C above 1990 levels (with regional variability in the degree of warming).
- Changes in the variability of temperatures at a range of scales from daily to decadal.

- Changes in average precipitation and larger year-to-year variation in precipitation.
- An increase in the amplitude and frequency of extreme climate events.
- Continued retreat of glaciers and ice caps.
- Continued rise of global mean sea level by 0.09 to 0.8 m between 1990 and 2100.

In addition to these gradual changes in climate patterns and the Earth's climate-driven systems, there are also some projections concerning the additional risk of "singular events" e.g. shut down of the North Atlantic thermohaline oceanic circulation. Although clearly of high potential impact the probability of such events is considered to be very low (EEA 2004a) and so their potential impact on biodiversity will not be considered in this paper. However, it should be noted that such singular events may represent key areas of uncertainty, and new research might make it necessary to modify predictions concerning their likelihood (e.g. Bryden et al. 2005).

2.3 Climate change in Europe

Europe has warmed more rapidly than the global average temperature, with a 0.95°C increase since 1900. During the same period northern Europe has experienced a 10-40% increase in precipitation whilst southern Europe has experienced a decrease of up to 20%.

The average European temperature is projected to increase by 2 – 6.3°C (Parry 2000) but as with global temperatures this is likely to vary on a regional basis. The exact nature of this variation depends upon the particular model used, though many of the common scenarios indicate that warming is likely to be greatest over southern countries (Spain, Italy, Greece) and north-eastern areas (western Russia), and less along the Atlantic coast. With the exception of southern Europe, winters are expected to warm more rapidly than summers (EEA 2004a).

Changes in the salinity of oceans may also result from climate change, and may impact upon the biodiversity of marine systems either directly or through impacts on ocean circulatory systems. Curry et al. (2003) conclude that, in the Western Atlantic, there have been shifts in the oceanic distributions of fresh and saline waters that are consistent with a link to climate change. In the Mediterranean, major water masses exhibit a 40-year trend of increasing temperature and salinity (Roether et al. 1996). As well as climate-mediated changes in salinity and temperature, greenhouse gas emissions are currently leading to increases in ocean acidity – CO_2 is being absorbed from the atmosphere by the oceans which in turn lowers their pH; this acidification is likely to continue as atmospheric CO_2 concentrations continue to rise (The Royal Society 2005).

Projections also show a 1-2% per decade increase and up to 1% per decade decrease in precipitation in northern and southern Europe respectively. However, there will again be seasonal variation in these changes, with most of Europe experiencing wetter winters and an increase in the amount of rain rather than snow (EEA 2004a). It is likely that droughts and heavy precipitation events will increase in frequency, whilst the frequency of extremely cold winters will decrease (Christensen & Christensen 2003, EEA 2004a).

Throughout the rest of this paper the phrase "climate change" is taken to mean anthropogenically driven changes in climate.

3. THE IMPACT OF CLIMATE CHANGE ON EUROPEAN BIODIVERSITY

The global biodiversity resource is under threat from a range of anthropogenic drivers, including pollution, land use change and climate change (CBD 2003, Millennium Ecosystem Assessment 2005). Although it has previously been proposed that land use change is the most serious threat to global biodiversity (e.g. Sala et al. 2000) recent work has suggested that climate change may be as great a long term threat to species survival (Thomas et al. 2004), although this work is not without its uncertainties (Thuiller et al. 2004). Irrespective, there is "very high confidence" (as determined by the IPCC criteria) that climate change is already impacting on biodiversity at a global scale (Parmesan and Yohe 2003)

Information on the impact of climate change on European biodiversity comes from two main sources. Firstly there are those instances where this impact has already been detected. Such information commonly comes from long-term monitoring of species or ecosystems. Secondly there are projections of the future impacts of climate change using modelling techniques.

3.1 Observed climate change impacts on European biodiversity

3.1.1 Terrestrial ecosystems

European plant species are showing a shift toward earlier bud burst and flowering times (particularly early-blooming and herbaceous species), UK butterfly species are appearing earlier, amphibian and bird species are breeding earlier and migrating bird species are arriving earlier during the season (Walther et al. 2002 and references therein). Between 1962 and 1995 an analysis of phenological[1] data in general indicates an increase in the length of the growing season by about 10 days (Menzel & Fabian 1999) and the overall trend toward a longer growing season is consistent with an increase of about 12% in the "greenness of the vegetation" (Zhou et al. 2001, EEA 2004a). These European responses mirror the results of global studies that show a marked shift toward earlier spring events (Parmesan & Yohe 2003, Root et al. 2003). Climatic control of autumn phenology is more complicated, involving a heavier reliance on light cues, and autumn phenological processes have not shown such a consistent relationship to temperature increases (Walther et al. 2002, Root et al. 2003). Importantly there are geographic variations in these responses, with delayed rather than earlier onset of spring phases in south-eastern Europe (Walther et al. 2002).

Winter survival of some common bird species, including grey heron, buzzard and song thrush, has increased due to an increase in winter temperatures (Frederiksen 2002 in EEA 2004a). Such increased population densities can drive shifts in species distributions (also called species' ranges). In addition, because each species has a limited set of physical conditions that it can tolerate, climate change can also directly impact on species distributions (for example warming can make some sites unsuitable

[1] i.e. timing of biological events

for existing species but suitable for new species from warmer environments). Globally there have been consistent shifts in species distributions either poleward or toward higher altitudes in a variety of taxonomic groups (Walther et al. 2002). There is evidence that birds in the UK have responded to recent increases in temperature by shifting their ranges northwards (Thomas and Lennon 1999). UK butterflies have also shown signs of a northerly shift in range, but the potential increase in abundance from a northern shift of range margins is counterbalanced for many species, particularly habitat specialists (who tend also to be poor dispersers), by lack of suitable habitat and the negative impacts of habitat fragmentation (Warren et al. 2001). This highlights the important interactive effects of climate change and other biodiversity drivers such as land use change and pollution. There is also evidence of range changes in European vascular plants. Walther et al. (2005) demonstrate that a northerly shift in the distribution of holly (Ilex aquifolium) is associated with increased temperatures. Although not discussing range shifts per se, Preston et al. (2002) in an analysis of the changing flora of Britain and Ireland, highlight a trend toward a relative increase in native species with a wide, southerly European distribution and a decrease in species with a very northerly European distribution. However they find the evidence of an association with climate change inconclusive. Similarly long-term monitoring of plant communities in the Netherlands and Norway have shown reductions in groups of plant species adapted to "cold" environmental conditions, and an increase in those adapted to "warm" conditions (EEA 2004a and references therein).

Climate-driven changes in ranges may be influencing species' behaviour and morphologies, although evidence of this type of effect is less common. Two UK butterfly species have increased the variety of habitat types that they colonise, and two bush cricket species have increased proportions of dispersive (long-winged) individuals in recently founded populations (Thomas et al. 2001). These responses will likely improve the ability of these species to track climate, and may be an impact of climate change on biological selection (although they may also be an adaptive response to other drivers of range shifting).

Arctic and alpine systems have provided strong evidence of climate change impacts on terrestrial biodiversity, perhaps because of the important regulatory impacts of climate, particularly temperature, in these systems (Chapin & Körner 1995). In European mountain environments there has been a clear upward shift of the distributional limits of plant species (e.g. Grabherr et al. 1994), including the location of the treeline (Kullman 2001). Because of the negative relationship between temperature and vascular plant diversity in arctic and alpine systems these upward or northerly shifts in species ranges lead to an increase in diversity within plant communities. However, this is at the expense of those species that are out-competed, for example a range of specialist arctic/alpine lichen and moss species (Molau and Alatalo 1998). Despite the majority of evidence indicating an upward shift in species distributions in mountain systems, there has been a recent decrease in the altitudinal limits of vegetation zones on mountains in the Faroe Islands due to a cooling trend (Fossa 2003), demonstrating regional variability in climate change across Europe. A major recent study, the Arctic Climate Impact Assessment (ACIA, 2004a), has reviewed the past and likely future impacts of climate change on arctic environments, and highlights that in some arctic and subarctic European areas important vascular plant species may be in decline. The indigenous knowledge of Saami reindeer herders indicates that marshy systems are drying in northern Finland, and that important berry species have reduced abundance in many areas.

3.1.2 Coastal and marine ecosystems

There is clear evidence for the responsiveness of coastal and marine ecosystems to climate. For example previous warming of the north Atlantic from 1920 to 1960 (due to natural climatic variability) led to a northerly expansion of a range of marine organisms, from plankton to commercial fish such as cod and herring (EEA 2004b). Changes in phenology, species' distributions and community composition in some components of marine ecosystems can be attributed directly to climate change.

Data obtained from the Continuous Plankton Recorder have demonstrated a long-term increase in the abundance of phytoplankton in two ocean regions, the central northeast Atlantic and the central North Sea, and a decline in phytoplankton abundance in the north northeast Atlantic. The increased abundances are associated with increasing sea-surface temperatures whilst the zone of decreased abundance is associated with an area of cooling (Reid et al. 1998). This cooling region lies to the west of the Faroes and, as with the decline in vegetation zones on Faroese mountains, demonstrates the spatial variability of climate change impacts. Plankton data also show that, for those plankton species that use temperature as a signal for initiation of growth and reproduction, seasonal events are occurring earlier in the year (Edwards and Richardson 2004), mimicking shifts in terrestrial systems towards an earlier spring. However, increased sea surface temperatures do not always lead to increased plankton abundance – warming may have negative impacts. Although warmer temperatures in the Northeast Atlantic have led to increased abundances of phytoplankton in cooler regions, they have also led to decreased abundances in warmer regions, an effect that is propagated up the marine food web (Richardson and Schoeman 2004). Similarly a number of warm-water copepod species have undergone a northerly latitudinal shift of up to 10 degrees in the eastern North Atlantic and European shelf seas, whilst cold water species have declined in abundance, changes associated with an increasing warming of the northern hemisphere and changes in the North Atlantic Oscillation (see Beaugrand et al. 2002 for details of species). In the Mediterranean Sea a range of species that were previously thought of as having a southern distribution appear to be extending their ranges into the northern areas, species that were previously active only in summer are now present throughout the year, and species associated with cooler waters are now being found at greater depths (Boero 2005).

Although it may be assumed that marine systems contain fewer constraints on the potential for species to migrate in response to climate change, dispersal limitation can restrict the response of some marine species. For some benthic organisms the distance between suitable habitat may be too great for larvae survival and successful migration (Hiscock et al. 2004). Genner et al. (2004) showed that although there were similar climate change-driven effects on the composition of fish assemblages in two spatially separate marine regions (the Bristol and English Channels), within each region a different subset of species has responded to climate change. This suggests that local environmental drivers, local interactions or restraints on dispersal prevent synchronous climate change responses in populations in the two regions.

Although changes in range in response to climate change in European terrestrial systems normally involves northerly movement, in marine systems, because of the flow of currents around the coast, the patterns are more complex. In the English Channel the warm-water barnacle Balanus perforatus and the topshell Osilinus lineatus have extended their ranges eastwards by over 100 km in the past 25 years, and another warm water barnacle, Chthamalus montagui has extended its range southwards in eastern Scotland. These eastward extensions in the English Channel and the southerly extension in Scotland reflect flows of water from the southwest around Britain and Ireland (Hiscock et al. 2004 and references therein).

3.2 Predicted climate change impacts on European biodiversity

This section summarises the predicted future impacts of climate change on European biodiversity. It combines the results of modelling studies, manipulation experiments simulating certain aspects of climate change (e.g. warming), and expert synthesis of available information. It also discusses some of the key areas of uncertainty with respect to predicting the future impacts of climate change on biodiversity.

Throughout this section we use three documents in particular – the Convention on Biological Diversity technical report on “Interlinkages between Biodiversity and Climate Change” (CBD 2003), and the European Environment Agency report on “Impacts of Europe’s Changing Climate” (EEA 2004a) both of which draw heavily upon the Intergovernmental Panel on Climate Change assessments (Houghton et al. 2001); these documents will not be referenced in this section but the reader should realise that they have been important sources of information throughout.

In all cases there is uncertainty surrounding the prediction of future climate change impacts on European biodiversity. Some of this uncertainty is related to future social and economic trends – economic and social development, including the response of society to climate change, will have profound impacts on biodiversity. For example some impacts of climate change will be mediated through changes in agricultural or fisheries practice in response both to climate change and changes in policy or practices driven by other forces. To deal with this type of uncertainty researchers often discuss “scenarios” rather than predictions (e.g. Houghton et al. 2001, ACCELERATES 2004). A scenario describes the potential impacts of climate change given a particular socio-economic trajectory.

3.2.1 Terrestrial ecosystems

The greatest effects of climate change on terrestrial systems are expected in arctic regions and the moisture-limited ecosystems of southern and eastern Europe and the Mediterranean.

Continued phenological changes will occur; many ecological studies have demonstrated the strong link between climate and the timing of biological processes irrespective of climate change (e.g. Forchhammer et al. 2001, Frederiksen et al. 2004b). General predictions include increased growing season length in northern areas (e.g. Scandinavia) and decreased growing season length in southern areas (particularly at low altitudes) as a consequence of water limitation.

Even in the absence of changes in species distribution, changes in phenology and the length of the growing season and productivity would lead to changes in the species composition of communities. Extended growing seasons will lead to increased biomass production in northern areas (Scandinavia and northern Russia), whilst in southerly regions productivity will likely be reduced. Increased productivity in a system will lead to changes in the relative dominance of species. Those species that were previously constrained by low temperatures in northerly systems will now become relatively more dominant. For example there is likely to be an expansion of shrub and tree species into currently open subarctic and arctic tundra areas (ACIA 2004a), as already detected in the Alaskan Arctic (Sturm et al. 2001), whilst some previously dominant species in southerly systems would decline in abundance due to water-limitation and drought (ATEAM 2004, Schröter et al. 2005). Assuming other factors remain unchanged, winter survival of some bird species (and likely other species) will continue to increase towards northern range margins, again leading to changes in the composition of communities.

In addition to increasing competition, excessive temperatures and low water availability, some impacts of climate change on community composition might be extremely subtle and operate over a longer time span. For example a decline or loss of frost events would prevent fruit initiation and the onset of flowering and fruit formation in some plant species (RHS 2005). This in turn would prevent successful reproduction under environmental conditions to which the adult plant would otherwise appear well-adapted. Changes in the variability of climate may also have negative impacts on biodiversity. Increased seasonal variation in climatic conditions and frequency of extreme events may amplify population fluctuations leading to rapid extinctions of some rare species.

Further changes in distribution will occur and will contribute to changes in community composition. Dynamic vegetation models (DGVMs) indicate that distributions of major species groups and biomes are likely to shift polewards and toward higher altitudes (ACIA 2004a, Diversitas 2005). In the European Arctic region there will be a northward movement of boreal forests. High arctic environments on the European mainland however will suffer from a lack of potential for northward migration, being trapped between expanding southern vegetation zones and the Arctic Ocean (Callaghan et al. 2004). Arctic species will have significant difficulties migrating across the sea between northern Norway and the Svalbard archipelago, Iceland and the Faroes (Callaghan et al. 2004), although human activities may aid the dispersal of species.

In Scandinavia it is predicted that there will be a 40-60% reduction in the current mountain vegetation area (Holten and Carey 1992 in EEA 2004a). Mountain species are likely to be particularly at risk because of the impact of altitudinal migration on the potential for latitudinal migration and the enforced reduction of habitat area with increasing altitude (Gottfried et al. 1999, Körner 1999). The upward migration of the treeline may lead to the loss of some mountain endemics, although the exact response of the treeline to climate change is difficult to predict (Dullinger et al. 2004).

Modelling scenarios indicate that plant species will move in a north-easterly direction, with a large turnover of plant species in many areas. In the model of Bakkenes et al. (2002) the most dramatic areas of species loss are in Spain and South-western France, although the model did not account for possible influx of species from northern Africa. Increased frequency of fire events in Mediterranean ecosystems is seen as a major driver of species loss from these environments, and contributes to their predicted high vulnerability (ATEAM 2004, Schröter et al. 2005). Thuiller et al. (2005) also found significant species turnover, dependent in particular on changes in temperature and moisture conditions, with the boreal region projected to lose the fewest species and the Mediterranean and Euro-Siberian regions predicted to lose the most species.

Vulnerability is the “degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity” (Houghton et al. 2001). The vulnerability of many European species may increase, and the significance of European countries with respect to biodiversity conservation may change (ACCELERATES 2004, Harrison et al. in press, Thuiller et al. 2005).

Importantly, communities are not expected to shift as unaltered units. There is likely to be significant disruption of communities because of: 1) species-specific responses to altered climatic conditions, 2) the impacts that these have on interactions between species, 3) different dispersal abilities between species. In plant communities, weedy and invasive species may have an advantage because of their high dispersal ability and utilisation of disturbed habitats - increased disturbance events (for example forest fires and erosion) will result from an increased frequency of extreme weather events. However, systems dominated by long-lived species such as woodlands might be slow to change. Although modelling scenarios indicate that the lengthy time taken by trees to reach reproductive maturity would limit their distributional response (MONARCH2 – Berry et al. 2005), trees might persist within a site for a prolonged period, despite the potential impact of climate on vulnerable life stages such as seedlings. The consequences of climate change for the regenerative potential of such communities would become evident only very slowly.

Changes in the frequency and intensity of rain events may influence freshwater ecosystems, leading for example to changes in flow rates and flow variability in streams and rivers and thus their suitability for particular species. In particular habitats that already have limited hydrological connectivity (e.g. headwaters, ditches and ephemeral ponds) may be further fragmented by reduced precipitation and are perhaps most sensitive to changing climatic conditions (PRINCE 2005). The impact of climate change on precipitation and temporal run-off patterns will be spatially variable across Europe. Modelling scenarios indicate a general reduction in run-off in southern Europe, and an increase in the north. IN large parts of eastern Europe higher temperatures reduce the amount of precipitation falling as snow, thereby leading to increased winter and reduced spring run-off levels (Arnell 1999)

Many freshwater species have a limited range of temperature tolerance, and changes in temperature regime in freshwater systems will have considerable impact on key ecological processes, including reproduction and development, species interactions, migration of species across ecosystems and the potential invasion of exotic species (PRINCE, 2005). Warmer water temperatures, both directly and through their impact on oxygen availability, will reduce habitat availability in lakes. These impacts are expected to be particularly serious for northern-latitude freshwater fish species. Terrestrial impacts of climate change might also affect freshwater systems. For example in peatland areas warmer temperatures and reduced precipitation might lead to increased decomposition of the peat and increased release of nutrients, which could in turn lead to eutrophication in lake and river systems and thus changes in species composition. Increased decomposition, as a result of drying, will also enhance CO_2 release from peatland areas. Changes in rainfall patterns will impact upon wetland areas and the numerous species of birds, both year-round residents and migratory species that are dependent upon them.

Uncertainties exist with respect to these scenarios. Some of these uncertainties originate in the complexity of biological processes and our incomplete understanding of them: although we have a broad understanding of the likely patterns, we do not know precisely how biological systems will respond to climate change drivers. In addition some uncertainties arise from and involve the response of society to climate change and the impact that this societal response has on other key drivers of biodiversity, for example agriculture, fisheries and CO_2 concentrations.

Biotic interactions and their response to climate change represent a major area of uncertainty with respect to species responses. Future range shifts may lead to disjunction between commonly co-occurring species (Root et al. 2003). Range shifts may also create novel species combinations with unpredictable outcomes. For example, Hódar and Zamora (2004) found that increased winter temperatures lead to an upward altitudinal migration of pine processionary moth in the Spanish Sierra Nevada. As a consequence the range of the moth now overlaps with that of relic populations of Pinus sylvestris subsp. nevadensis which has suffered severe defoliation. Furthermore, as demonstrated by the adaptive changes in butterflies and crickets discussed above (Thomas et al. 2001), species are not consistent unchanging units - they may themselves change in response to selective pressures from range shifting.

The response of soil communities and soil processes to climate change represents another key area of uncertainty with respect to the function of biotic systems. Soil processes will be strongly influenced by both warming and changes in rainfall patterns. Emmett et al. (2004) conclude from a large-scale, multi-site manipulation experiment, that key soil processes will be differentially affected by changes in temperature and rainfall and that, given our current understanding, the impact of climate change on soil processes is hard to predict.

Increased atmospheric CO_2 concentration may either have a positive or negative effect on primary productivity depending upon the region, the type of vegetation and the scenario of climate change. Such predictions are complicated by the impact of CO_2 concentrations on plant water use efficiency. Changes in CO_2 concentration may alter the competitive balance between plant species but it is likely that a subtle interaction of plant physiology, and changes in water availability and temperature will determine the outcome of these changing community dynamics. In addition future changes in CO_2 concentrations will themselves be influenced by biodiversity responses. Feedbacks exist between biodiversity, ecosystem processes and global climate. Key amongst these is the storage of carbon through photosynthesis in plant biomass and soils. It was previously thought that increasing temperatures in Europe would lead to an overall net gain in the total amount of stored carbon, but recent research suggests that the amount of stored carbon within soils may already be decreasing in a manner consistent with a climate-driven mechanism (Bellamy et al. 2005), and that warmer summers and associated water limitation may be off-setting the positive effects of earlier springs and extended growing seasons (Angert et al. 2005). Modelling studies also indicate a total overall decrease in terrestrial carbon sink strength (ATEAM 2004).

In terms of uncertainty with respect to societal responses, changes in agricultural practice are likely to have significant consequences for the impacts of climate change on terrestrial biodiversity and its capacity to adapt to climate change (Berry et al. 2005). Changes in temperature and precipitation could alter the distribution of particular types of agricultural practice. In the long term the area suitable for agriculture will likely shift north, with expansion of more intensive agricultural practices in northerly latitudes and at higher altitudes, and agricultural abandonment in drier Mediterranean regions. However the response of agriculture may be particularly complicated, linked as it is to numerous environmental, economic and social drivers. The prediction of societal responses to climate change has involved coupling formal modelling processes with expert judgement, as in the development of the IPCC SRES scenarios of societal responses to climate change (e.g. ACCELERATES), and several projects have integrated land-cover and climate change within predictive modelling approaches (ACCELERATES 2004, MONARCH 2 - Berry et al. 2005). These indicate that climate change impacts on biodiversity might be mitigated to some extent by changes in agricultural practice, but this in turn depends on the degree of regulation of agriculture (ACCELERATES 2004).

Finally, many human activities, including agriculture, tourism and urbanisation, lead to an increasingly fragmented and impermeable terrestrial landscape over which it is difficult for species to migrate in response to climate change (Warren et al. 2001, Travis 2002). It may already be the case that numerous species are attempting to track their preferred climatic conditions but are unable to do so because of the impacts of a fragmented landscape, either directly on their own migration rate or indirectly through limitations on the migration of other species upon which they depend (Thomas 2003, Donald 2005) – contraction of southern range margins may not be matched by expansion of northern range margins (Honnay et al. 2002). Even in apparently pristine environments, such as the Arctic, human impacts on the landscape can be substantial. Human impacts can be detected from 4-10 km from human infrastructure in the Arctic (a much wider zone of impact than in more temperate regions). Between 50-80% of the Arctic could be impacted by infrastructure developments by 2050 (Nelleman et al. 2001 in Callaghan et al. 2004) leading to an increasingly fragmented and impermeable landscape. Again the degree of future landscape fragmentation, and the ability of species to move through the landscape, will be dependent upon social and economic developments within the coming decades.

3.2.2. Coastal and marine ecosystems

In marine systems, as in terrestrial systems, there is a sizable body of evidence demonstrating the strong links between climate and biological processes (e.g. Frederiksen et al. 2004a, b, Hiscock et al. 2004, Cotton et al. 2005, Worm et al. 2005) indicating that future climate change will impact on most species within marine environments. However, because of the cyclical nature of the North Atlantic Oscillation (NAO), and the clear regulatory impact of the NAO on many marine systems (e.g. Durant et al. 2003, 2004) long-term change may be initially obscured by NAO cycles (Hiscock et al. 2004). In addition variation in the NAO is not independent of climate change. UKCIP scenarios indicate an increased frequency of a positive NAO index (McKenzie Hedger et al. 2000) and consequently a predominance of westerly weather (Hiscock et al. 2004).

Changes in the length of growing and breeding seasons, community composition and species ranges are all likely to continue under future climate change. Increasing temperatures will continue to alter the timing of the marine growing season, leading to further changes in timing of plankton blooms and the potential for trophic mismatch between the activities of primary producers and higher levels within the food chain (Hiscock et al. 2004). Furthermore there is likely to be a poleward shift of marine species leading to an increase in the abundance of warm water species and a decrease in the abundance of cold-water species in any particular area. Since some key commercial fish species, e.g. cod, are both top predators and cold-water species, the combination of range shifting and trophic mismatch will have serious consequences for the sustainability and range of some commercial fisheries. Fisheries may have to move in order to track the changing distribution of key species.

Changes in species' distributions will occur through a range of different mechanisms and different species will have different capacities to move. For example, some southerly species will cease to be constricted by lethal low winter temperatures and will respond positively, with increased breeding success and survival leading to increased population size, whilst those relying upon low temperatures as reproductive cues will have reduced reproductive success (Hiscock et al. 2004), and consequently may become less abundant and die out. Sessile (attached to the sea floor) southerly seabed species with short-lived larva and without a mobile phase will increase in abundance where they occur at present, but will not respond with a rapid extension of their northerly range limit, whilst free-swimming species are likely to be much more responsive (Hiscock et al. 2004). Furthermore the expansion of populations in situ may limit the availability of space for species migrating in to an area, and so restrict the range shifting capacity of otherwise rapidly-responding species. (Hiscock et al. 2004). Importantly human activity may have a strong influence on the movement of species. An example of this can be seen in the Lessepsian migration of species from the Red Sea through the Suez Canal to the Mediterranean Sea. The ability of Red Sea species to expand into the Mediterranean may be enhanced by increased temperatures – climate change interacts with increased mobility of species due to human activity. Introduction of invasive species by human activity is common in both terrestrial and marine ecosystems, and the influx and expansion of invasives during climate change may have serious consequences for the survival and migration of native species.

Different species within coastal and marine communities may utilise climate cues operating at different scales (Frederiksen 2004a). A high degree of spatial variability in climate change impacts would lead different species within the same community to respond differently to climate change, and would increase the loss of existing community structure. Differential responses to a given change in temperature are also likely to alter community composition – for example not all species of marine algae have similar thermal responses and so a given change in sea temperatures and differences in the degree of temperature change in summer and winter will lead to species-specific responses (Hiscock et al. 2004 and references therein). However, there may be a significant lag between climate change and the response of species composition, for example in benthic communities where long-lived adult stages can survive even though they are unable to successfully reproduce – these individuals will occupy space and prevent species turnover (Hiscock et al. 2004).

Shoreline areas will be affected by increased storminess and windiness: the distribution of some shoreline habitats may be altered or reduced purely by these effects. The positive effects of increased temperatures, for example on the growth of some fucoid algae (i.e. seaweeds that resemble Fucus species), may be offset by the negative impacts of increased disturbance from strong swells (Hiscock et al. 2004). In addition sea level rise will significantly impact on the distribution of coastal habitats. The combined pressure of coastal development and sea level rise could also reduce the availability of intertidal habitats.

Again, there is a wide range of uncertainties associated with the exact detail of the impacts of climate change on coastal and marine biodiversity. The complexity of marine responses to climate is demonstrated by a climate-driven regime shift that occurred within the North Sea during the 1980s. A wide range of species from a range of trophic levels were affected and the regime shift, initiated by changes in hydro-meteorological forcing, involved a complex set of intermediate physical mechanisms and occurred over a number of years (Beaugrand 2004). Interactions are again likely to mediate the impacts of climate change in marine systems. Some species are keystone structural species that create habitat. Their loss would lead to the complete loss of dependent species from a system (Hiscock et al. 2004) and a “step-change” in community composition.

As in terrestrial systems enhanced atmospheric CO_2 concentrations are likely to interact with climatic drivers to determine species distributions. Enhanced CO_2 concentrations and the subsequent acidification of ocean waters are likely to affect the process of calcification by which key marine species, including corals and components of the phytoplankton and zooplankton, produce structures from calcium carbonate. Our understanding of the impact impacts of ocean acidification, and its interaction with climate change, is currently very poor, and it is difficult to predict how marine systems will respond to the combination of these drivers (The Royal Society 2005).

Finally the links between exploitation of marine systems and climate drivers will be extremely important in determining long-term biodiversity trends (Worm et al. 2005), but these relationships are not well understood and their future projection is complicated as it necessitates inclusion of socio-economic scenarios.

3.3 Summary - impacts and uncertainties

Observed impacts:

- Earlier spring events (with regional variation).
- Increased over-winter survival.
- Changes in species distributions northwards or upwards (in mountain areas) but dependent on species characteristics.
- Decline in “cold” species and increase in “warm” species.
- Evolution in response to altered competition, promotes distributional change.
- Negative responses in already warm systems (due to water limitation).
- Interaction of climate change drivers with other effects e.g. habitat fragmentation or biodiversity exploitation.

Predicted impacts & response scenarios

- Continued phenological changes – increased growing season length (and productivity) in the north and decreased in the south.
- Changes in species distributions, northerly and upward, but dependent on dispersal ability including habitat availability and species traits.
- Disruption of communities.
- Increased disturbance by extreme events.
- Increased prevalence of “weedy” species – high dispersal ability and survival in disturbed environments.
- Turnover of species, with increased vulnerability for many species and changes in the relative conservation importance of European areas.

Uncertainties

The major uncertainties with respect to the future impacts of climate change fall in to several broad categories:

Firstly there is the level of detail with which scenarios can be created. Although modelling approaches concur with respect to large-scale responses, for example northerly shifts of species, major uncertainty exists with respect to the exact detail of changes and this in turn reflects our lack of understanding with respect to the structuring and functioning of ecosystems. For example, in order to make finer scale predictions of the response of species to climate change, important biotic factors such as dispersal ability, evolutionary responses and the role of biotic interactions will need to be considered, as these regulate the occurrence of species at a finer scale within the landscape. The species-specificity of responses is also a major component of this uncertainty. For example although there is, overall, likely to be a northerly movement of species, there will be wide variation in this response at the species level because of the different ways in which species perceive and respond to climate, and also because of species-specific variation in dispersal ability.

Secondly the timescale over which species will respond is a major source of uncertainty. Species are likely to respond at different rates not least because of their differing life cycles. A slow-growing, infrequently reproducing species will have limited capacity to track climate relative to a fast-growing, widely-dispersing species. In addition it is difficult to estimate how quickly species can move through a landscape and hence the level of spatial range shifting response we could expect within a given timeframe, for example 50-100 years. Timescale uncertainty is also linked to the problem of our limited understanding of biological processes. Unpredictable biological processes such as evolution and novel interactions may influence the rate of response even whilst that response is occurring

Thirdly climate change will not be operating on biodiversity in isolation. Climate change will lead to societal and economic responses and change, as will future economic and political development. This in turn will influence the development of a wide range of sectoral activities that in turn influence biodiversity, both in terms of its status and its capacity to respond to climate change. Human activities will also have unexpected consequences that will impact upon biodiversity. For example the increased capacity of long-distance dispersal of species because of human activity is increasing the number of aggressive invasive species within European ecosystems, and the expansion of these invasives may alter during climate change and impact upon the survival of native biodiversity. Invasive species may include pest and disease vectors, and their impact on food supply and human health will have societal and economic consequences (EPBRS 2005). Another key anthropogenic driver that will influence biodiversity responses to climate is enhanced atmospheric CO_2 concentrations, which will interact with climate impacts on biodiversity in both marine and terrestrial ecosystems. Finally a natural driver of biotic processes - day length - will remain unchanged. Northerly shifts will enable species to track a particular climate window, but species will move from their current day-length window. These are examples of the final area of major uncertainty - understanding the interactive effects of climate change with the wide range of other drivers of biodiversity, and in turn predicting future changes in these drivers as well as in climate.

Fourthly, non-linear future responses are possible. Current trends in populations and ranges are based upon historical datasets. However, an important feature of current climate scenarios is that they are placing natural systems within a climate context that they have not previously experienced, both in terms of the combination of climatic variables and increased frequency of extreme events. Therefore trends based upon historical datasets have reduced power in predicting future responses, and it is possible that these future responses will involve non-linear responses that deviate from past trends as novel combination of environmental conditions occur (EPBRS 2005).

Overall, therefore, we have an understanding of the likely responses of biodiversity at a very broad scale, i.e. there are likely to be certain responses such as northerly range shifting and changes in community composition, but uncertainty is related to the detail, i.e. which species will move where and how quickly. This uncertainty is a consequence of a general lack of understanding involving the influence of biological processes and external drivers and their interactive effects.

4. POLICY RESPONSES TO THE IMPACT OF CLIMATE CHANGE ON BIODIVERSITY

In this section we briefly review the main threads of past, current and future policy that are relevant to promoting the conservation of biodiversity in a changing climate. Such a review helps to identify possible barriers to knowledge flow between researchers and policy makers, highlights upcoming opportunities for the development of policy to promote biodiversity conservation under climate change and provides some focal points for potential research activities.

4.1 Current policy

Within Europe, biodiversity conservation and climate change policies are implemented at the national level, and it is difficult to get a pan-European overview of the current status of such national policies (Message from Malahide 2004, EEAC 2005). However, the development of these policies is often guided by or stems from international (global or European) conventions, treaties and commitments. In this section we will therefore focus on key European and international climate change and biodiversity policy developments that have taken place, are currently being implemented or are planned for the future.

4.1.1 Biodiversity policy

A number of Conventions and Directives have determined the development of biodiversity policy across Europe. In particular these include the 1971 Ramsar Convention on the protection of wetlands of international importance, the 1979 Bonn Convention on migratory species, the 1979 Bern Convention on the conservation of European wildlife and natural habitats, the 1979 EC Birds Directive and the 1992 EC Habitats Directive (including the conservation of habitats and wild flora and fauna). All of these agreements call for the maintenance of environments, habitats or species in what is considered to be a “favourable” state, and where species or habitats are currently in an “unfavourable” state for action to be taken to improve the situation. Signatory nations have an obligation to protect particular species and habitats listed under the Habitats and Birds Directives, and the development of Natura 2000, a European Union-wide network of nature conservation sites, was initiated through the Habitats Directive.

Clearly a major development with respect to biodiversity conservation at a global scale is the Convention on Biological Diversity (CBD), whose objectives are the conservation of biodiversity, the sustainable use of its components and the equitable sharing of the benefits of the genetic resources. In 1998, as a response to commitments under the CBD, the European Commission adopted a Communication on a European Community Biodiversity Strategy (ECBS). The ECBS has four associated action plans which specify how to implement the strategy in particular areas of European Community activity: conservation of natural resources, fisheries, agriculture, and economic and development co-operation.

The CBD established an AHTEG (ad hoc technical expert group) on Biological Diversity and Climate Change in 2002. Its report, focussing on advice on the integration of biodiversity considerations into the implementation of the UNFCCC and its Kyoto Protocol was published in 2003 (CBD 2003). A second AHTEG of the CBD was established in 2005 to undertake a supplementary assessment on the integration of biodiversity considerations in the implementation of adaptation activities to climate change (CBD 2005c).

In 2001 at the Gothenburg Council the EU Heads of State and Governments made a commitment to “halt the decline of biodiversity by 2010”, going further than the general commitment at the 2002 meeting of the Parties to the CBD to “the achievement by 2010 of a significant reduction the current rate of loss of biological diversity”. The same 2001 Gothenburg Council also adopted the EU Sustainable Development Strategy (EUSDS) which has the headline objective “to protect and restore habitats and natural systems and halt the loss of biodiversity by 2010”. The 2003 Kyiv Resolution extends the 2010 EU commitment to the pan-European region. The Pan-European Biological and Landscape Diversity Strategy (PEBLDS) was developed with the aim of achieving the commitments made under the Kyiv Resolution, with a particular focus on eastern Europe.

However, despite these commitments recent reviews have highlighted a continued worrying decline in the status of the European biodiversity resource. These negative trends have led to strong calls for a recommitment within Europe to tackling the problems of biodiversity loss, most notably through the Message from Malahide (2004), which lays out priority objectives and detailed targets to meet the EU 2010 commitment. The European Commission is currently preparing a “Biodiversity Communication” in response to the Message from Malahide, a draft of which was scheduled for examination by the Biodiversity Expert Group in December 2005 with the expectation that it will be ready for adoption in May 2006 (EU Nature Directors 2005).

4.1.2 Climate change policy

The United Nations Framework Convention on Climate Change (UNFCCC), like the CBD is a product of the 1992 Rio Earth Summit. The Convention provides a framework for intergovernmental efforts to tackle the challenge posed by climate change. Signatories to the convention are committed to producing national strategies for addressing greenhouse gas emissions and adapting to expected impacts. Even at the time of initiation of the UNFCCC it was clear that the commitments it contained would be insufficient to tackle the threat of climate change. Therefore, in 1995, parties to the convention launched a new round of talks to decide on stronger and more detailed commitments for industrialized countries. After two and a half years this led to the adoption of the Kyoto Protocol in December 1997. The Kyoto Protocol is an international and legally binding agreement. Parties to the protocol are committed to targets to limit or reduce their greenhouse gas emissions. The protocol finally entered into force on 16 February 2005, and under the Protocol, the EU committed itself to reduce greenhouse gas emissions by 8%. In June 2000 the European Commission launched the European Climate Change Programme (ECCP), with the goal of the identifying and developing the necessary elements of a EU strategy to implement the Kyoto Protocol. The Second European Climate Change Programme (ECCPII) was launched in October 2005, with the aim of providing a new policy framework for EU climate change policy beyond 2012. Over 450 stakeholders attended the launch of the new programme and discussed a number of key policy areas including a review of ECCPin the EU, aviation, passenger road transport, geological carbon capture and storage and adaptation.

The development of the UNFCCC has been closely linked with the activities of the Intergovernmental Panel on Climate Change (IPCC). The IPCC was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). The IPCC was tasked with providing independent scientific advice on all issues related to climate change, and was asked to produce a report on climate change and its impacts in order to help the development of realistic response strategies. The first assessment report of the IPCC served as the basis for negotiating the UNFCCC. Subsequent assessment reports have been used as the basis for international policy development and research activities. The IPCC is currently in the process of developing the remit and scope for its fourth assessment report, which will be due for publication in 2007.

4.2 Developing future policy

4.2.1 Mitigation and adaptation

Two main types of policy can be used to deal with the impacts of climate change - mitigation and adaptation.

Mitigation policies attempt to limit further changes in global climate. Mitigation policies either focus on reducing the emission of greenhouse gases through, for example, more efficient energy use or cleaner energy production, or on enhancing greenhouse gas sinks. The latter approach includes land use, land-use change and forestry activities – or LULUCF activities. These comprise a) conservation of existing carbon pools, i.e. avoidance of deforestation, b) sequestration by increasing the size of carbon pools, e.g. through afforestation and reforestation and c) substitution of fossil fuels by biomass production (CBD 2003). The ECCP focuses on the concept of mitigation; the activities of the ECCP “will comprise mitigation of emissions through policies and measures and the flexible mechanisms, capacity building/technology transfer, research/observation and training and education” (EC 2000). Mitigation of climate change would in principle be beneficial for biodiversity – a lower level of climate change will have a smaller impact on biodiversity. However, climate change mitigation activities may themselves have negative impacts on biodiversity that must be considered when mitigation options are assessed.

Although mitigation activities are already underway it is becoming increasingly clear that, even with the most optimistic projections of the level of mitigation that can be achieved, we are still going to suffer from a significant degree of climate change

(Pallemaerts et al. 2005). For example, to meet the target of stabilising atmospheric CO_2 concentrations at 450 ppm, global emissions of CO_2 must peak in the year 2015 (IUCN 2005) and this is highly unlikely. Therefore to cope with the current and future change we need to develop adaptation strategies, i.e. strategies that optimise the outcome of those changes that occur. Adaptation activities are already being developed and implemented for agriculture and other sectors. Adaptation strategies are also being developed at the national level in certain EU Member States. The UK for example started its process of formulating a UK adaptation strategy to climate change in 2005 with a consultation aimed at businesses and industry asking for information on strategies already in place. In another example, the Finnish government identified the need for a national strategy for climate change in 2001, and has recently published a document addressing different sectors, actions to improve adaptive capacity and take advantage of activities associated with climate change (Martilla et al. 2005).

With respect to biodiversity conservation, adaptation strategies would be designed to enable the maximum biodiversity resource to persist within the context of a changing climate. Some of these adaptations might be autonomous, i.e. systems responding to climate change without any active management intervention. This could include species dispersal and colonisation of new areas or in situ evolutionary responses. In contrast planned adaptation involves active intervention and management, for example promotion of dispersal by the development of habitat "corridors" or the more strategic design of landscapes to facilitate the movement of species

4.2.2 Challenges and targets for the development of policy

Until recently policies dealing with the potential impacts of climate change focussed strongly on mitigation (e.g. the ECCP). However there is now a widespread recognition of the urgent need to develop adaptation strategies in all sectors, as highlighted in the development of the framework for the 4th IPCC Assessment (IPCC 2005) and during the recent Greenland Dialogue (Pallemaerts et al. 2005, Greenland Dialogue 2005), and more specifically with respect to the conservation of biodiversity, as discussed at a meeting on "Climate Change and Biodiversity Conservation in Central and Eastern Europe sponsored by the German Federal Agency for Nature Conservation (Vilm, Germany, May 31- June 4, 2005), and recent meetings of the EEAC (Oxfordshire, UK, 7-10 September 2005), an AHTEG of the CBD (Helsinki, Finland, 13-16 September 2005), and the EPBRS (Aviemore, UK, 2-5 October 2005).

Development of the major components of European biodiversity policy (e.g. Natura 2000) does not appear to have explicitly incorporated the predicted impacts of climate change on biodiversity. For example the ECBS focuses on the threats to biodiversity from intensified land use, habitat fragmentation and pollution, whilst the 2001 Gothenburg Council commitment and the 2003 Kyiv Resolution do not include new activities to specifically adapt to the impacts of climate change on biodiversity, although adaptation is likely to be a necessity in order to achieve these commitments. This situation may have arisen because only very recently has the scale of the threat to biodiversity from climate change become apparent (with the assessments of e.g. Walther et al. 2002, Parmesan et al. 2003, Thomas et al. 2004). However the importance of explicitly considering the threat to biodiversity from climate change has recently been strongly voiced and the need for policy responses to this threat is now widely recognised and accepted (e.g. CBD 2003, 2005c, Message from Malahide 2004, ACIA 2004b, EEAC 2005, EPBRS 2005, EU Nature Directors 2005, IUCN 2005).

It is not necessarily the case that changes to existing policy are needed in order to take action to protect biodiversity from climate change. As discussed, the main biodiversity conventions and directives commit European countries to maintaining their biodiversity resource in a “favourable” state. Such a commitment remains in place even during the course of climate change, and thus there are perhaps already policy drivers promoting the development and uptake of climate change mitigation and adaptation strategies for biodiversity conservation. However, the degree to which existing legislation is sufficient to cover the activities that will be needed during climate change is still a moot point. Although some commentators have concluded that existing policy is sufficient (Watts in Monkhouse & Miller 2005, EU Nature Directors 2005), it has also been strongly argued that existing legislation is too heavily orientated toward the concept of reserves and conservation in situ (for example in the development of the Natura 2000 network). This approach is suited to a static environment but does not cope well with large-scale species dispersal as expected under climate change (see for example Accelerates 2004, Callaghan et al. 2004, RHS 2005). It is likely to be necessary to modify the philosophy and management associated with protected areas and to see them as core areas within a permeable landscape through which species are moving – protected areas would provide propagules for the movement of species from an area and act as focal points for the arrival and establishment of new species. Furthermore “the designation of protected areas should be based more on the systemic properties of the while landscape than on the individual attributes of candidate sites” (ACCELERATES 2004). However, such a change in philosophy would also likely encompass a change in the characteristics of protected areas and consequently any associated policies.

It is clear that some existing policy frameworks already explicitly promote the concept of holistic management of landscapes and seas. A key target of the PEBLDS is the integration of Natura 2000 and other site-oriented approaches into a genuinely networked landscape that enables species migration. Therefore, the debate over the adequacy of existing policy might not be arising from its scope, but rather from the way in which it is implemented. As discussed, although policy may be developed at an international level its implementation is dependent upon national legislation and policies. It is currently unclear how effectively existing policy is being translated into national legislation, and consequently whether it is the policy or its implementation (or both) that might need to be adapted to cope with climate change impacts on biodiversity. This issue has been realised in recent calls for reviews of the state of biodiversity policy across Europe (e.g. EEAC 2005), but even without such a review there is already evidence that policy implementation might be a significant issue. A recent EEA assessment examined Environmental Policy Integration (EPI) in EU member states (EEA 2005a, b). EPI is a process to ensure that environmental issues are reflected in all policy making. Article 6 of the CBD requests each party to “integrate as far as possible and as appropriate, the conservation and sustainable use of biological diversity into relevant sectoral or cross-sectoral plans, programmes and policies”. According to Article 6 of the European Community Treaty “environmental protection requirements must be integrated into the definition and implementation of the Community policies and activities (…) in particular with a view to promoting sustainable development”. The EEA assessment indicates that although “governments have taken great strides in terms of developing and agreeing high-level political commitments to environmental policy integration and sustainable development” there is “little evidence of NSDSs [national sustainable development strategies – a key mechanism for achieving EPI] being implemented” (EEA 2005a). This would suggest that at present, and despite the aims of the ECBS, there is only limited current movement toward consideration of biodiversity issues in general (outside of the biodiversity conservation sector) let alone the more specific consideration of climate change impacts on biodiversity, as pointed out by the Message from Malahide and forthcoming Biodiversity Communication. Why might this inertia to EPI exist? This is a critical question. It is clear that maximising biodiversity conservation during climate change will need the consideration of biodiversity issues in the development of mitigation and adaptation strategies in all sectors (EEAC 2005, IISD 2005), and that this will depend upon effective EPI.

The EEA assessment indicates that one key barrier to EPI is that biodiversity conservation must compete in the policy arena with other sectors such as economic and social development (both of which are given a higher policy priority), and that it is perceived that biodiversity conservation will impose a cost on social and economic development. However, the economic worth of the biodiversity resource may be greatly underestimated in such assessments – in some instances up to 40% of economic output may depend on ecosystem services (CBD 2005a). A thorough understanding of the genuine cost of biodiversity loss and the economic benefits of biodiversity conservation is therefore critical in raising the profile of biodiversity conservation on the policy agenda. As stated by Watson (2005) “There is an urgent need to demonstrate that there is no dichotomy between economic growth and environmental protection”. Ultimately it is necessary to deal with the perception that “non-action is a cheaper alternative” (EEA 2004a).

Furthermore the cost of developing and implementing adaptation and mitigation strategies for biodiversity conservation during climate change may be less than perceived, and importantly may be reduced by making use of synergies in policy development in many sectors. Any policy adaptations that promote the favourable status of species and habitats are likely to be of benefit in conserving diversity in a changing environment, either by producing a robust ecosystem that may be able to adapt to climate change in situ or by providing a good supply of propagules capable of dispersing and tracking the climate window. Sectors where it is clear that climate change adaptation will have biodiversity implications, and where there may be capacity for synergistic activities, include agriculture and rural development, water management, energy, and those sectors influencing coastal and marine environments (EU Nature Directors 2005). Careful analysis of proposed sectoral adaptation and mitigation strategies may indicate possible benefits for biodiversity that could be incorporated with little or no extra cost. A recent EEAC statement called for the investigation and development of such synergies (EEAC 2005), and instruments are currently being developed with the specific aim of addressing the difficulties of integrating biodiversity considerations in to adaptation and mitigation policies in other sectors (e.g. Choudhury et al. 2004, CBD 2005a). Such integrated approaches will necessitate better “national coordination among sectoral agencies to design policy measures that exploit potential synergies between national and economic development objectives and environmentally focussed projects and policies” (CBD 2003).

The conservation of biodiversity is often integrated into other sectoral policies through the concept of sustainable development, i.e. for continued economic development to be sustainable, ecosystem services provided by natural systems must be underpinned by conservation of a robust biodiversity resource (EEA 2005a, Millennium Ecosystem Assessment 2005). The importance of such integration is reiterated in Objective 2 of the Message from Malahide (2004). However, the integration of sustainable development within EU policy is the aim of the EUSDS, which has been criticised because of a lack of clarity concerning the concept of sustainable development and associated targets, objectives and deadlines (EEA 2005b, Monkhouse & Miller 2005).

It must be recognised that despite the importance of biodiversity for economic development, sectoral adaptation policies are already being implemented without full regard to their consequences for biodiversity. It is this problem as much as the need to develop adaptation strategies for biodiversity per se that led to the establishment of the 2005 CBD Ad Hoc Technical Expert Group on biodiversity and adaptation to climate change. In agriculture, for example, potential adaptations include the introduction of drought tolerant, salt tolerant, higher temperature tolerant or pest resistant varieties, introduction of extending multi-cropping or mixed farming systems, introduction of new crop or animal species, changes in timing and type of irrigation and fertiliser use and the abandonment of agriculture. Our understanding of the impact of these and other adaptation activities is very poor (CBD 2005b, 2005c).

It should also be acknowledged that adaptation policies designed to conserve biodiversity might have negative consequences, which will have to be managed. Activities that lead to greater movement of species across landscapes to allow them to adapt autonomously to climate change will also facilitate the spread of invasive species.

Finally, it is hard to assess whether existing policy (or its implementation) is adequate to encompass new developments designed specifically to adapt to or mitigate the impacts of climate change when it is not yet clear exactly what form such developments might take. To resolve this issue it might be necessary to define more explicitly what mitigation and adaptation activities are needed, to consider how these would translate in to management actions “on the ground”, and then to assess whether the existing policy framework is able to support and promote them.

4.3 Summary – policy responses

In summary there would appear to be a number of activities, some related to further research and some related to changes in institutional behaviour (which might itself be the subject of research activity), all of which could promote biodiversity conservation during climate change. These include:

- The detailed design and testing of adaptation and mitigation strategies that might be put in place to promote biodiversity conservation in a changing climate (see also section 5.2),
- The assessment of the adequacy of existing legislation with respect to its capacity to encompass mitigation and adaptation strategies to deal with the threat of climate change, and the efficacy with which such legislation translates in to appropriate action “on the ground”,
- The assessment of developments in policy from all sectors with respect to impacts on biodiversity and the potential development of synergistic outcomes promoting biodiversity conservation,
- A higher priority for biodiversity considerations in the policy arena, supported by more detailed and accurate costings of the economic value of biodiversity and associated ecosystem services and a better definition of the concepts of sustainable development.

These activities are closely interlinked – the development of detailed proposals for adaptation activities would enable costings to be developed and the potential for synergies with other sectoral policy developments to be assessed, which in turn would influence the likelihood of the adoption of that policy. However, current policy developments including the current reviews of the ECBS and EUSDS, along with the development of the framework for the 4th IPCC assessment, may enable these issues to be rapidly integrated into the policy agenda.

5. GAPS IN KNOWLEDGE, RESEARCH PRIORITIES AND BARRIERS TO KNOWLEDGE TRANSFER

The review of the impacts of climate change on European biodiversity and the state of current biodiversity policy presented in the previous sections have highlighted gaps in knowledge with respect to the future impacts of climate change on biodiversity, and the implementation of adaptation and mitigation strategies to conserve Europe's biodiversity resource during climate change. These sections have also discussed barriers to knowledge transfer that, along with gaps in knowledge, may be preventing the implementation of adaptation strategies.

In this section we combine this information with that from the electronic-conference 'Climate Change and Biodiversity Conservation: Knowledge needed to support development of integrated adaptation strategies', 29 August – 16 September 2005, and a number of other major recent meetings (EEAC 2005, EPBRS 2005, CBD 2005c, EU Nature Directors 2005). We discuss major gaps in knowledge that may currently be preventing development of adaptation strategies, how such gaps might be addressed (therefore providing a list of potential research activities), and how barriers to knowledge transfer might be overcome. This section integrates information from a wide range of sources, including many of the documents already referred to in this paper. For brevity and clarity we will not include references within this section. The output of the EPBRS electronic conference can be found at:
http://www.nbu.ac.uk/biota/Archive_climatechange/index.htm

Each section presented here ends with a summary of the main priorities for research and action. Although we have tried to find a simple structure for this information, many of these issues are closely interrelated and separating them into neat categories is not a simple task. For example monitoring and predicting climate change impacts will provide information with respect to the relative vulnerability of different systems, which in turn will lead to prioritisation of certain habitats with respect to mitigation or adaptation activity.

5.1 Climate change impacts on biodiversity

A substantial amount of good quality scientific information already exists relating to climate change and climate change impacts on biodiversity. Databases and information sharing, made public by integrated networks, are helping towards making this information more accessible. However, access to this information can be costly in terms of money and time. A major priority is therefore to create digitised bibliographic information (i.e. detailing available scientific literature and information) in searchable databases. This will help in preventing duplication of research, reduce the time spent in data gathering and support the provision of information on climate change to the public and policy makers.

Improved monitoring is seen as key to developing our understanding of climate change and its impact on ecological systems. Monitoring will help to separate short-term localised effects from longer term trends. Exactly how cost-effective, broad-scale, long-term monitoring should be designed (including the issue of data standardisation) is, however, an issue requiring further attention. Part of the monitoring process should concentrate on the characteristics of the physical environment (e.g. ocean pH and salinity, meteorological conditions) as well as the components of biodiversity. Closely linked to monitoring efforts is the need to understand the extent of existing biodiversity resources: - assessment of change necessitates a good baseline from which to begin. Monitoring biodiversity might also have benefits in raising the awareness of a broader stakeholder community about the impacts of climate change. For example, participatory monitoring of phenological processes is already gaining widespread notice in the media, for example the UK Phenology Network, and is enabling different stakeholder groups to become actively involved in research, breaking down the perceived barriers between the research communities and other stakeholder groups.

Despite recent advances there is still a need for research on the impact of different aspects of climate change on biodiversity, including extreme events. Experimental research studies commonly focus on the impacts of changes in temperature but, as discussed, changes in rainfall and water availability may be critical. Changes in the evapotranspiration balance may have greater impacts on species than temperature alone. Research in this field should include gathering information on the response of individual species to water availability and developing models of regional hydrological regimes, thereby providing an assessment of regional sensitivity of biodiversity to changes in water availability. As the frequency and intensity of extreme weather events is likely to increase, understanding the ecological responses to these events and interactions with land use change and water resource management is essential for the formulation of adaptation strategies.

Understanding climate change impacts on poorly studied but potentially crucial systems (e.g. soil communities), species and habitats continues to be a priority. In some systems we still have very limited understanding of the fundamental processes that regulate biodiversity, let alone how biodiversity in these systems will respond to climate change. Priority should be given to those systems that are both poorly understood and likely to be vital in delivering ecosystem services. Making an explicit link to ecosystem services is important in improving knowledge transfer from the scientific to the policy communities (as discussed in sections 4.2.2 and 5.5).

The inability to predict responses of biodiversity at finer scales (or at least to provide fine-scale scenarios for biodiversity change with high levels of certainty) is currently a block to the development of adaptation strategies. A problem associated with the development of models to allow downscaling is the lack of data at the appropriate scale (Berry et al. 2005). Although difficult, localised predictions of biodiversity responses would also help to make biodiversity impacts of climate change more relevant to a wide range of stakeholders. The production of such predictions will need to include an understanding of the role of processes such as habitat fragmentation, biotic interactions, and species-specific variation in migratory and evolutionary capacity. Currently we have a poor understanding even of the generality and potential scale of impact of these processes and how they might modify predictions from commonly utilised modelling approaches. When addressing the question of scale we need to consider both scale within the landscape i.e. predicting impacts at local as opposed to regional or national level, and within species groups, i.e. predicting impacts at the level of individual species and genotypes rather than, as is generally done at present, very broad groupings. Given the totality of species involved we need to consider the scale at which science can be applied – we will not be able to predict the response of all species and have to accept that predicting the response of functional groups or key indicator, threatened or charismatic species is likely to be the most effective use of resources.

The need to understand interactions between processes regulating biodiversity is becoming very apparent. Interactions will occur between different pressures and drivers of biodiversity, including climate change, habitat loss, the spread of alien invasive species and land use change. Socio-economic developments will have both direct (e.g. exploitation, habitat fragmentation) and indirect (e.g. CO_2 and nitrogen pollutant mediated) effects that will interact to determine biodiversity responses. The interactive effects of processes operating within the same community but at different temporal and spatial scales are poorly understood. There are science initiatives already in place to address some of these issues but large levels of uncertainty are associated with the future impacts of these interactive effects.

Process-based models using laboratory and/or field data may be able to account for important interactions within ecological systems. Plant functional types and insect functional groups have already been used to predict responses to climate change. A traits-based approach to predict climate change impacts on biodiversity might be a possibility. Taking the example of the impacts of climate change on insect populations, responses to climate change might be predictable using a combination of life-history traits including mobility, intrinsic rates of increase, voltinism (the number of generations produced in a year), feeding guild and tolerance to stresses. Another option is to focus less on individual species and distribution patterns and more on landscape level processes. However, despite the fact that process-based models may be a useful approach, they may be impractical to employ in some instances due to the complexity of ecological processes and the potential importance of random events.

The established approach of Bioclimatic envelope modelling of species distributions (wherein a range of climate parameters are fitted to the existing distribution of a species and, using future climate scenarios, the possible future distribution of the species is then calculated) will still be needed, for example in the screening of large numbers of species or plant functional types to CO_2/temperature interaction. Improvements in bioclimate modelling should include refinement of traditional methods using better data, and an ensemble forecasting approach, i.e. to compare predictions from a range of independent models to help reduce uncertainties and develop agreement on current and future trends. Another approach is to develop “hybrid” models combining bioclimate ‘envelope’ and mechanistic modelling with explicit mechanistic and correlative components. Ultimately there is a need to develop a more integrated modelling approach that plays on the strengths and accounts for the weaknesses of the different techniques available. There remains a lively and constructive debate amongst scientists about the most appropriate modelling techniques, which in itself stimulates further work. It is likely that a range of approaches will be used for the foreseeable future, and effort will be needed to communicate potentially conflicting findings to policy users.

Finally there is a need to recognise and understand the links between biodiversity and human health. These links range from the diffuse, e.g. the provision of ecosystem services, to the specific, for example changes in the distribution of pest and disease vectors during climate change. These latter species will have direct and immediate impacts on society and the economy. Understanding the response of these vector species should be a priority for biodiversity research.

Summary of priority activities:

- Digitised bibliographic information available in searchable databases
- Long term monitoring, including design of new monitoring frameworks, adequate baselines
- Examination of a range of climatic drivers, especially rainfall
- Investigation of the climate responses of poorly understood systems likely to be crucial to providing ecosystem services (e.g. soil systems)
- Prediction of biodiversity responses at a finer scale, integrating the impact of key biological processes
- Understanding the interactions between processes in regulating biodiversity
- Continuing development of modelling approaches that incorporate the impacts of multiple drivers of biodiversity change, included integrated approaches
- Understanding and predicting the response of key pest and disease vectors

5.2 Development of adaptation strategies for biodiversity conservation

Identifying those ecological systems that are most vulnerable to climate change (including semi-natural and fragmented habitats) will be a key step towards developing adaptation strategies, providing opportunities to increase resilience of ecological systems to climate change. This process should help to define levels of “dangerous interference” and set mitigation targets for greenhouse gas concentrations in the atmosphere that take account of climate change impacts on biodiversity. They should also guide the task of landscape-scale planning for biodiversity conservation by identifying structures and features that are necessary to promote certain components of biodiversity (e.g. key habitat features that are associated with rare species). This work should also include research on habitat needs of migratory species.

The first steps toward outlining how adaptation strategies might be implemented need to be taken. We must ask how such strategies will translate in to activities “on the ground”. In order to start sketching out such strategies a number of key research themes that will inform our understanding of how to create resilient ecosystems and permeable landscapes need to be addressed. These include identifying time scales for the creation of different types of key habitats in new areas, establishing the edge effects of intensive land uses on semi-natural habitats, understanding the factors that promote resilience, and developing land management practices that increase the permeability of different land uses to biodiversity (whilst controlling the spread of unwanted invasive alien species). Once initial adaptation and mitigation strategies for biodiversity conservation during climate change have been formulated they should then be monitored and supplemented by the appropriate data to refine them as needed.

The existing networks of protected areas will be a critical component of adaptation strategies. There is a need to take a more flexible and adaptive approach to management of protected areas, both in terms of improving their ecological connectivity to create a more permeable landscape and in terms of assessing their capacity to cope with the impacts of climate change. For example there is a need to develop and evaluate the effectiveness of policies and practices that aim to improve the quality and connectivity of the surrounding matrix. Since agriculture and forestry are common land-uses of this matrix , options for strengthening incentives for farmers and foresters to conserve biodiversity and promote species dispersal, need to be considered (Donald 2005). However little is known about practical aspects of managing species dispersal and colonisation in highly fragmented European ecosystems, different species have different capabilities and requirements and, in some cases, the conservation objective may be to prevent colonisation by undesirable species.

Development of “first-step” adaptation strategies would enable an assessment of whether existing biodiversity conservation policy is adequate to enable the activities needed to protect biodiversity during climate change. International cooperation on this issue is important in some areas, especially with respect to the dispersal of species between administrations. This poses a challenge for existing, locally determined land use and resource management planning. Is there are need for a common strategy for European spatial development that can be effectively implemented at the regional landscape level in addition to Natura 2000? Associated with this issue is how best to incorporate ecological knowledge into planning processes. One possibility might be a combination of eco-regional and national conservation planning. It should be noted that some projects are already starting to address such issues. For example BRANCH (funded as part of the EU INTERREG scheme) aims to “identify, develop and advocate spatial planning mechanisms to help the adaptation of terrestrial and coastal biodiversity to climate change across North West Europe”, and is aiming to develop policies and strategies to assist future spatial planning in the task of accommodating climate change impacts on biodiversity (BRANCH 2005).

Despite the growing scientific evidence, ineffective communication and institutional inertia means that there is still a lack of policy response to climate change impacts on biodiversity. There is a need for interdisciplinary research to address the development of policies that can deliver conservation goals on a broad geographical scale and for the development of an institutional framework capable for delivering appropriate incentives for stakeholders to conserve biodiversity.

Summary of priority activities:

- Identifying vulnerable ecosystems including assessment of migratory routes
- Research to enable the design of adaptation strategies – e.g. how do we create resilient ecosystems within a permeable landscape?
- Implementation of adaptation strategies associated with their monitoring and ongoing refinement
- Assessment of the protected areas approach within the context of climate change – how will existing areas cope and how might they be integrated into an ecological network?
- Assessment of whether existing biodiversity legislation encompasses activities needed to adapt to climate change impacts

- Guidance on effective, shared approaches for spatial development that incorporates the likely impacts of climate change on biodiversity and integrates ecological knowledge into the planning process at different scales

5.3 Marine and coastal ecosystems

There is a requirement for long-term and broad-scale monitoring to track change and to be able to separate short-term variability from long-term trends and impacts of localised human activities from climate change. The design of long-term monitoring and research networks needs to be further developed. There should also be a comprehensive assessment of status and health of existing systems focussing on local and regional perspectives, as well as the identification of pressures adversely affecting marine and coastal biodiversity (e.g. fisheries activity) so that action to reduce the pressure can be prioritised.

Monitoring and assessment needs to be carried out together with process-orientated research on the underlying mechanisms enabling better predictive ability of rates and scales of likely future changes. Experimental studies (laboratory and field) should be carried out to test the reaction of organisms to likely effects of climate-induced change and therefore better understand what aspects of climate change are most important in threatening ecosystem structure and functioning. Specific experimental studies could include the assessment of the rate of atmospheric CO_2 conversion into biomass, impacts of temperature and saturated CO_2 levels on carbon fixation of individual species and the influence of temperature and salinity at organizational and functional levels of different species. Another very serious gap in knowledge at present is the rate of ocean acidification and the impacts it will have on biodiversity.

Predicting climate change impacts on biodiversity in marine and coastal ecosystems will necessitate the development of new tools, and ways to constantly update and integrate new methods and technologies as they develop. In addition the multi-trophic responses that need to be considered over a range of spatial and temporal scales will need the integration of current research efforts.

Summary of priority activities:

- Long-term broad-scale monitoring
- Assessment of current status of marine biodiversity and pressures impacting biodiversity that could be reduced
- Process-oriented research in to key drivers of change and response of ecosystem structure and function
- Better understanding of the impacts of ocean acidification
- Integration of current research efforts

5.4 Sectoral responses

One of the biggest threats to biodiversity may be the adaptation and mitigation activity that is currently under way in a wide range of sectors, which has not taken in to account potential impacts on biodiversity. There is clearly a need to identify all policies and practices already in place for adaptation to and mitigation of climate change in different sectors, and to assess their potential impact on biodiversity so that alternative approaches can be developed if needed. In addition there is a need to assess the effectiveness of existing adaptation strategies. What is the ecological, economic and social effectiveness of different adaptation strategies (including legislation) in relation to conservation and other sectoral goals? The development of methodologies to determine the economic value of the biodiversity resource will be an essential part of making information-based judgements on the choice of adaptation activities, and in promoting the integration of biodiversity conservation in sectoral adaptation strategies.

In the agricultural sector, there needs to be a better understanding of the role of biodiversity at the process level (especially in cropland soils), further development of future scenarios of agricultural land-use and management, process studies (both modelling and experimental) to couple the carbon and nitrogen cycles and a more complete biogeochemical/physical/socio-economic assessment of GHG mitigation options in agriculture. In forestry systems research priorities include understanding the variability and extremes of future climate scenarios in order to plan future forest production systems and modelling the potential for reducing extinction rates/increasing population sizes of species in forests through altering the management systems. Future changes in the energy sector might have considerable direct impacts on particular ecosystems. For example the mooted return to nuclear power, and the development of new nuclear generating schemes, irrespective of debates over the long-term storage of waste material, would likely impact upon already threatened coastal marginal ecosystems (since such energy production is often based at coastal sites). Renewable energy sources (e.g. wind, bio-fuels, and tidal power) will also all have environmental impacts which need to be fully understood - for example how will we promote biodiversity and a permeable landscape in the presence of large monoculture woodlands grown for biofuel production? As we have discussed changes in rainfall patterns and the availability of water will directly impact upon biodiversity. The needs of biodiversity conservation in aquatic and wetland systems (as well as the need to maintain carbon storage in soils and peatland systems) will have to be balanced with increasing demands for domestic and commercial water supply, especially in those areas where increased temperatures become a limiting factor for crop production. The ecology of heavily regulated water bodies such as canals and reservoirs are already strongly influenced by factors other than climate – human activity will be critical in determining the response of biodiversity in these ecosystems to multi-sectoral demands during climate change (PRINCE 2005). Finally all forms of development (including tourism) will impact upon biodiversity, not least by fragmenting the landscape. Perhaps one of the major mitigation activities would be minimising development in areas where there are likely to be limitations in terms of water and food supply, thereby minimising the conflict between biodiversity conservation and other sectors. In all these instances there need to be clear consideration of how the mitigation or adaptation activities might impact the response of biodiversity to climate change.

Summary of priority activities:

- Broad scale multi-sectoral assessment of adaptation and mitigation strategies and development of an effective institutional framework to promote biodiversity conservation
- Assessment of economic value of the biodiversity resource

- Scenarios of future sectoral development e.g. agricultural, forestry, water resource and energy sector development, under climate change (including understanding the impact of increased climate variability)
- Improved understanding of the coupling of the carbon and nitrogen cycles within agricultural systems
- Interdisciplinary research approaches

5.5 Barriers to knowledge transfer and priorities for science communication and co-operation

Although a substantial amount of information exists indicating that climate change is already having and will continue to have significant impacts on biodiversity, possibly preventing achievement of the target of halting biodiversity loss by 2010, the integration of biodiversity conservation into adaptation and mitigation strategy development is poor. There is still a lack of genuine cross-sectoral policy development to promote biodiversity conservation. This would suggest that barriers other than a lack of information are inhibiting the development of such strategies.

Interdisciplinary research in climate change studies is a key priority. Scientists have to overcome the challenges of interdisciplinary research (and integrating different kinds of knowledge, including local knowledge) by developing methods to quantify uncertainty and assess risks and communicating results directly to governments and indirectly to other policy-influencing actors through interactive networks. The integration of social and economic sciences have to be encouraged and developed especially when addressing the links between society and nature, and to improve communication between science and society. Workshops integrating scientists from a variety of different countries provide a better basis for scientists and policy-makers from different countries to encourage adaptation and biodiversity conservation across different land use sectors and apply lessons learned across countries.

Overall the impacts of climate change on biodiversity and the degree to which autonomous and directed adaptation will lesson these impacts are likely to be complex and hard to predict. This make its difficult to communicate existing or new research information to the people who will be required to act on this information, namely ecosystem managers, resource managers, the public and policy makers. The level of uncertainty associated with these predictions also limits managers' willingness to act on this information. However, there is a strong case that, given the rate of change and potential scale of impacts, action should be taken now (EEAC 2005, EU Nature Directors 2005). Because we have an imperfect understanding of the functioning of ecosystems mistakes are likely to be made, but the absence of complete understanding should not be used as an excuse for inactivity. The scientific community should be prepared to give the best professional judgements based on the available scientific evidence to enable urgent action. However, in order to promote the provision of this advice and its implementation into action a "no blame" culture should be adopted – we must accept that mistakes will be made. For such a culture to work it is vital to explain to all stakeholders the need to take action, despite the potential for occasional failures, and to develop a consensus that supports this approach.

Owing to the current uncertainty it will be necessary to further develop and apply iterative management processes. Since decisions will need to be taken based on limited scientific information, initial choices of management practice and conservation policy may be sub-optimal. However, the process of implementing those initial choices will provide information that can be used to improve management and policy. To make use of this on-going learning process we need to have a system of iterative policy and management practice development i.e. review known evidence – consult - implement management practice - monitor outcomes - assess outcomes and review new evidence - share experience – consult - refine management practice etc. Policy will need to be sufficiently flexible, and its implementation driven at a local level and regionally tailored, in order for this iterative process to succeed.

Some scientists may see the communication process as a last-minute add-on. In general it is true that the science-policy interface is weak. Some successful mechanisms are already in place to bridge the gap. A number of ways to reach out to the "wider scientific community" exist including making comprehensive assessments (similar to IPCC), establishing links between government agencies and experts, and using the collective expertise of a scientific conference to provide advice on particular issues. However, scientists could do more, and may benefit from the help of professionals to develop the way in which their message is presented. Scientists need to be able and willing to provide and translate data and information to policy-makers, although "a delicate balance has to be found between honesty about the uncertainty of the results and the clarity of the message conveyed" (ATEAM 2004). At the same time policy-makers need to be willing or able to use the information provided. Improved science-policy interaction will ensure that (i) relevant research is given sufficient priority to be funded and (ii) the results of the research are effective in influencing the actions of the many stakeholders who may be asked to change their ways as part of the broader strategy for biodiversity and adaptation to climate change. Communication of scientific results should increasingly be seen as a legitimate form of scientific activity that will require systematic support, funding structures and economic incentives to scientists if it is to prosper. However it is encouraging to note that several, relevant, high profile projects have successfully and explicitly involved stakeholders in project development from the outset (e.g. ATEAM, MONARCH).

Finally there are some institutional barriers to the flow of information. Although scientific information may make its way into the policy arena it might not lead to changes in policy due to the difficulty of handling the uncertainty associated with predictions of the response of natural systems, the higher policy priority given to economic and social development, the vague definition of sustainable development and the lack of accurate calculations of the genuine economic value of biodiversity resources. Priority actions to address these issues include the assessment of potential synergistic outcomes from promoting biodiversity conservation in all sectors, clearer definition of the concept of sustainable development and the assessment of the economic worth of biodiversity resource. In addition it needs to be made clear that the socio-economic scenarios used in modelling represent genuine choices for society and that there is not an inevitably that we will pursue a particular path (ATEAM 2004),

Summary of key barriers and priority activities:

- Improved uptake of biodiversity issues into cross-sectoral policy development – assessment of capacity for synergistic policy development, accurate assessment of the economic value of biodiversity and a clarification of the concept of sustainable development.

- Interdisciplinary research may help to reach out to a broader spectrum of stakeholders
- Complexity and uncertainties are associated with the message – this represents a challenge for science communicators
- Action is needed now, but it will need a “no blame” culture and a supportive consensus
- Improved interactions at the science-policy interface require a two-way flow of information supported by legitimisation (funding and support) of science communication

As a final note it is worth pointing out that the proposals listed above will undoubtedly cost significant amounts of money. However, as pointed out by the recent EU Nature Directors meeting (EU Nature Directors 2005) with respect to the recent recommendations of the EPBRS (EPBRS 2005), the cost of implementing the research recommendations is small relative to the eventual societal costs of climate change impacts on biodiversity.

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APPENDIX 1 – Background papers for working groups at the EPBRS meeting “Climate Change and Biodiversity Conservation”, Aviemore, Scotland, 2nd-5th October 2005.

Understanding and predicting climate change impacts

I – Knowledge and action

1. There is substantial evidence of ongoing climate change impacts on biodiversity. Earlier spring events, increased over-winter survival, northerly or upward range shifting and a change in the dominant species within communities from “cold” to “warm” have all been observed in marine and terrestrial environments, and are occurring in a manner that suggests a strong link to recent rapid increases in temperature.
2. Predicted future impacts of climate change include continued phenological changes and northerly and upward migration of species. However these responses will be dependent on species-specific characteristics (e.g. reproductive rate, migratory capacity), which may evolve in response to a changing climate. The disruption of communities and increased levels of disturbance will favour “weedy” species with high dispersal ability and an affinity for disturbed habitats. The turnover of species in communities will alter the relative conservation value of different areas within Europe, and will increase the vulnerability of many species.
3. Future projections of biodiversity responses to climate change currently contain a wide range of uncertainties. These include: the problem of producing finer scale predictions of biodiversity responses which may be strongly influenced by biotic processes such as dispersal ability, interactions and evolution; non-linear responses within complex systems; the timescale over which species are expected to respond; the interactive effect of climate change with other key drivers of biodiversity (including social and economic drivers), for example developments in the agricultural and fisheries sectors, CO_2 concentrations, atmospheric nitrogen deposition, and unchanging variation in day length along the north-south latitudinal gradient.

II – Knowledge gaps

1. Substantial information exists but should be collated into digitised, publicly searchable bibliographic databases.
2. Monitoring and fundamental research of the biodiversity resource should be promoted, including the development of adequate baselines and understanding that encompasses poorly covered systems.
3. Modelling approaches should be combined to tackle the key issues in predicting climate change impacts on biodiversity. Both climate envelope and mechanistic modelling approaches have strengths and weaknesses – an integrated modelling framework could build on the strengths of both approaches. The potential impact of biological processes on the output of models needs to be systematically assessed.

4. Predicting biodiversity responses to climate change will clearly need an understanding of the future responses of all sectors – integrated scenario modelling is essential.

Adaptation – conservation policy and actions

I – Knowledge and action

1. Climate change will lead to a much more fluid context for efforts to conserve Europe’s biodiversity. The composition of communities and habitats will change. Many species are likely to attempt to move northwards or upwards and track their climate envelopes or the movement of other species upon which they depend. If they are to survive they will need to be able to migrate in this fashion.
2. The current site oriented approach will not cater for this movement – it concentrates on protecting species in situ. A key step will therefore be the development of permeable landscapes. However, although often proposed, it is still unclear exactly what actions should be taken to create this permeability. Exactly what would we do in the landscape to make them more permeable, and would the same activities be needed for all species? How can they be included in to planning processes?
3. There is also debate concerning the substantial existing biodiversity legislation – it is not clear whether this legislation will support the actions needed to adapt biodiversity conservation efforts to the threat of climate change.
4. Because of the interactive effect of multiple drivers in determining the response of biodiversity to climate change, and the likely need for adaptations in all sectors to promote biodiversity conservation during climate change, it is crucial that biodiversity conservation is fully integrated in to the policy agenda.
5. Action needs to be taken, but our incomplete understanding of natural systems means that we cannot precisely predict the outcome of our actions. We therefore need to implement a process of ongoing review and development of adaptation strategies that accepts that mistakes will be made and tries to learn from them.

II – Knowledge gaps

1. Particularly vulnerable ecosystems, habitats and species need to be identified as the focus for conservation efforts – species currently considered “safe” might be threatened by climate change.
2. Research efforts should support two main types of conservation activity: promoting the stability and quality of the biodiversity resource in situ, and developing methods for creating a permeable landscape.
3. Adaptation strategies should be developed which include a flexible approach to strategy review and update, as well as accepting that mistakes will be made.
4. Once a clearer understanding of the content of adaptation strategies is available, existing biodiversity legislation needs to be assessed to see whether it supports these strategies.
5. Biodiversity conservation needs to be fully integrated in to policy from all sectors. Crucial to the success of this will be accurate evaluations of the economic worth of biodiversity, a clearer definition of the concept of sustainable development, better interaction at the science-policy interface and changes in cultural practice within policy-making institutions.

Adaptation – sector responses (agriculture, forestry, water, energy etc)

I – Knowledge and action

1. Sectoral responses to the threat of climate change are increasingly being developed and many are already being implemented. In agriculture, for example, potential adaptations include the introduction of drought tolerant, salt tolerant, higher temperature tolerant or pest resistant varieties, introduction of new crop or animal species, changes in timing and type of irrigation and fertiliser use and the abandonment of agriculture. The energy sector will increasingly respond to climate change through the production of biomass crops. Infrastructural adaptations will include sea walls and the diversion of freshwater to areas suffering water shortage (dams or irrigation channels) or increased extraction of groundwater supply.

2. Action is needed to incorporate biodiversity considerations in all sectors. As a first step the impact on biodiversity of adaptation activities in each sector must be evaluated and biodiversity considerations incorporated at the earliest stages of relevant sectroral development activities.

3. For economic development to be sustainable, ecosystem services provided by natural systems must be underpinned by conservation of the biodiversity resource. The genetic diversity of many plant species, for example, provides a source of adaptation for the agricultural sector. Thus, the conservation of biodiversity should be further integrated into other sectoral policies through the concept of sustainable development.

II – Knowledge gaps

1. Existing knowledge on the impacts of existing and proposed adaptation activities should be synthesised in order to provide advice to all sectors and to identify specific knowledge gaps. Priority areas will include coastal zones and wetlands threatened by infrastructural adaptation such as sea walls and increased water extraction.

2. Ecological research should focus on quantifying the impact of existing and proposed adaptation activities on biodiversity.

3. Research on biodiversity should be integrated with relevant research in each sector. In forestry systems, for example, research includes the variability and extremes of future climate scenarios in order to plan future forest production systems, and on modelling the potential for reducing extinction rates/increasing population sizes of species in forests through altering the management systems adopted.

4. Interdisciplinary research is needed to evaluate the ecological, economic and social effectiveness of different options in order to develop adaptation strategies that meet sustainable development goals.

Adaptation in marine and coastal environments

I – Knowledge and action

1. Considerable impacts of climate change have already detected within marine ecosystems, including changes in the timing of biological processes, productivity and the distribution of species. There is regional variation in these responses: some areas have warmed whilst others have cooled. In some areas already considered "warm" further increases in temperature have led to decreases in productivity. Patterns of species movement and response to climate drivers are not straightforward, due to factors such as the flow of currents around coastlines and barriers to species movement.
2. Changes in the length of growing season, community composition and species ranges will all continue during climate change. Overall, warm water species are likely to replace cold water species, with cold water species moving to more northerly latitudes or greater depths. Changes in the timing of biological processes may lead to trophic mismatch and may have serious implications for all levels of the food chain. Increased storminess and sea level rises will lead to changes in coastal ecosystems and may lead to the erosion of existing coastal habitats.
3. Considerable uncertainties exist with respect to these predictions including: species-specific responses to climate including variation in the key drivers and scales over which they operate; the capacity of species from different marine and coastal habitats to migrate in response to a changing climate; the possible influx of new invasive species; the impact of increasing ocean acidity due to absorption of atmospheric CO_2; sectoral responses – for example, managed retreat to enable persistence of some coastal habitats might be inhibited by coastal development and construction of sea defences, whilst changes in fishing policy will substantially alter the pressure on the marine biodiversity resource.

II – Knowledge gaps

1. Fundamental ecological research is required to understand how different components of marine and coastal ecosystems respond to climate and other drivers of biodiversity, including fisheries, and the temporal and spatial scales over which these responses occur.
2. Monitoring marine and coastal ecosystems will be fundamental to this research effort.
3. The impacts of ocean acidification might be very great but are currently difficult to assess. This is clearly a knowledge gap that urgently needs to be addressed.
4. Current research need to be integrated in order to understand the complex multi-trophic responses of marine and coastal systems to climate change.
5. The impact of economic and social development on marine and coastal ecosystems means that integrated scenario modelling will be essential.

Knowledge Transfer

I – Knowledge and action

1. Although scientists and policy-makers have very different “cultures”, some successful mechanisms are already in place to bridge the gap between them, including the European Platform for Biodiversity Research Strategy (EPBRS), conferences on policy matters organised by Coastal Management for Sustainability and the Marine Life Information Network (MARLin), and contributions from scientists to various committees. However communication of scientific results to policy-makers remains a key challenge for the development of adaptation strategies for the conservation of biodiversity in a changing climate. Scientific data need to be made available to the scientific community, policy-making end-users and stakeholders in an accessible and digestible form in order for the information to be translated into rapid policy deliverables and ultimately into actions for the conservation of biodiversity.
2. Weaknesses exist at the science-policy interface as well as at the science-action interface, especially between data collection for scientific research and “what needs to be done”. Mechanisms need to be put in place to ensure that (i) the research is to be given sufficient priority to be funded in the first place; and (ii) the results of the research are to be effective in influencing the actions of the many stakeholders who may be asked to change their ways as part of the broader strategy for biodiversity and adaptation to climate change.
3. Interdisciplinary research is needed to overcome the challenge of integrating different kinds of knowledge, including local knowledge into adaptation strategies.

II – Knowledge gaps and research priorities

1. Identify barriers to knowledge transfer.
2. Develop methods to quantify and assess risk and uncertainty.
3. Develop methods to train and encourage scientists in science communication.
4. Develop interactive networks to communicate results directly to governments and indirectly to other policy-influencing actors.
5. Develop methods to facilitate access to scientific information.
6. Develop methods to promote inter- and trans-disciplinary climate change studies.
7. Develop methods to integrate local and scientific knowledge in the development of adaptation strategies for biodiversity conservation.

APPENDIX 2 – Recommendations of the meeting of the European Platform for Biodiversity Research Strategy

Held under the UK Presidency of the EU Aviemore, Scotland 2nd – 5th October 2005 on "Climate change and biodiversity conservation: Knowledge needed to support development of integrated adaptation strategies"

I – Knowledge and action

Climate change is being driven by human activities, and will accelerate despite current mitigation efforts. Having reviewed the available scientific evidence, the participants at this meeting conclude that:

(a) climate change poses an immediate challenge to the target of halting biodiversity loss in Europe, and to the successful implementation of Natura 2000, for the following reasons:

- there is firm evidence of biological responses to climate change: changes in flowering dates, arrival of migrating birds and fish; these and other phenological mismatches may disrupt ecosystems.
- there is strong evidence that the distribution of many species has responded to climate change. Very many species, however, are unable to disperse sufficiently rapidly to adapt to climate change in this way, especially in systems with low connectivity.
- there is evidence of changes in the composition and structure of communities and habitats, and in the habitat requirements of some species, including some protected species, pests and disease vectors.
- ecosystem processes and services are probably also altering as a direct result of climate change. Other drivers of biodiversity loss may exacerbate the rate and extent of these alterations and their reduction would offer the possibility of adaptation strategies.
- climate change may therefore stop us reaching site, regional, national and international conservation objectives. Furthermore, ecosystem goods and services, and their socio-economic benefits, will be put increasingly at risk.

(b) actions should be taken to:

- raise awareness of the impact of climate change on biodiversity and the need for adaptation policies and programmes in Europe. Monitoring of phenological phenomena can help to raise public awareness while providing early warning of the capacity of species to adapt to climate change.
- exploit existing knowledge to facilitate the natural dispersal of species, including habitat connectivity and ecological networks.
- review conservation targets in protected areas in the light of likely climate change impacts and the role of ecological networks for adaptation.
- implement the CBD Ecosystem Approach in developing large-scale, long-term adaptation and mitigation strategies to climate change.

- develop, and when available implement, dynamic adaptive conservation strategies integrating site and landscape/seascape-based approaches.

II – Knowledge Gaps

To support the above actions for adaptation, the participants at this meeting recommend that immediate steps are taken by relevant funding bodies, institutions and researchers to address the following gaps in knowledge:

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. This requires monitoring of abiotic factors and interactions with other drivers, at a range of spatial and temporal scales. Key features in terrestrial environments include CO_2, land use and nitrogen; and in marine environments, temperature, salinity, stratification, pH, currents, upwelling, stability and wave regime events.
- quantify and forecast the responses of genotypes, species, habitats, ecosystems, landscapes and seascapes at all relevant spatial and temporal scales. This requires: (1) enhanced understanding of the underlying mechanisms driving, and being driven by, these processes, (2) greater knowledge of the interactions among climate change and ecosystem components, structure, function and services; (3) improved quantitative comparison of observational, experimental and modelling approaches; (4) extended open access to data.
- improve understanding of the capacity of species and ecosystems to adapt to climate change. This should include assessment of the sensitivity and vulnerability of species and habitats, and consequences for ecosystem functions.
- 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. Develop strategies to increase ecosystem resistance and resilience.

Understanding socio-economic aspects of adaptation strategies

- further develop methodologies for evaluating adaptation and conservation policies. Refine methods for taking into account the socio-economic aspects of ecosystem goods and services, including consideration of the ethical, epistemological and methodological issues inherent in valuation of the natural world, and the ways in which valuations differ across stakeholder groups, cultures, space and time.
- improve understanding of the ways in which human factors influence the effectiveness of adaptation policies. Research is needed to understand how governance structures and human perceptions, values and attitudes impact on policy effectiveness, and to support development of improved systems of governance, including for seas and coasts, taking into account ecosystem goods and services.

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.

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;
- and further develop principles, legislation, guidelines, and practical techniques for management of land and sea, sectoral adaptation, and spatial planning.

III – Knowledge Transfer

The participants at this meeting are concerned that ineffective transfer of scientific knowledge is limiting the implementation of the adaptation strategies that are needed urgently to conserve biodiversity in the face of rapid climate change and therefore recommend actions are taken to:

- improve access to scientific data and information, ensuring that data is transformed into useful products for policy makers and other target audiences; using and further developing existing facilities, e.g. the CBD Clearing House Mechanism, GBIF, CORDIS, EIONET[2].
- promote, acknowledge and implement interdisciplinary global change research agendas involving a wide range of research and stakeholder communities, to stimulate exchange of ideas at the planning and delivery stages.
- develop tools to facilitate communication within and between sectors, ministries and institutions, and especially between climate change and biodiversity research and policy communities.
- establish mechanisms for effective communication to multiple stakeholders of the impacts of climate change, including the clear presentation of risk and uncertainties, and corresponding adaptations.

[2] Global Biodiversity Information Facility, Community Research and Development Information System, European Information and Observation Network

- engage stakeholders by raising awareness, understanding attitudes and sharing information, including participatory approaches to data collection and the shaping of adaptation strategies.
- encourage, support and train scientists to communicate with different audiences, including through participatory approaches.
- further increase the impact of scientific research by using communications and media specialists from outside the scientific community.
- improve the processes used to identify and overcome barriers to knowledge transfer within and between all sectors and between developed and developing nations, develop effective mechanisms for knowledge transfer, and review the effectiveness of existing science-policy interfaces.

APPENDIX 3 – Relevant excerpts from the EU Nature Directors Meeting held under the UK Presidency of the EU, Aviemore, Scotland October 2005

Session 2 – Thursday 6th October
Climate Change and Biodiversity – Learning to adapt

Opening statement

The session was opened with a keynote address from Jim Knight MP, Minister for Rural Affairs, Landscape, and Biodiversity at the Department for the Environment, Food and Rural Affairs. The minister thanked the hosts of the event and explained that the area for the meeting was ideal to explain the changes climate change would bring.

The Minister told the meeting that climate change was real and adaptation measures were required now. Decisions regarding conservation policies dealing with climate change must include people, be adaptable and flexible, integrate biodiversity and land-use and work in collaboration with other governmental policy areas. He hoped that this meeting would produce practical outcomes that encompassed these issues.

Discussion

Following his speech, the Minister took a number of questions on the issues raised. He agreed that the work being carried out by the CBD protected areas group was vital if developing nations were to implement adaptation policies. As the Presidency, the UK would establish the position on funding for the Montreal meeting and, in the light of that, send a communication to the CBD Secretariat on behalf of the Nature Directors expressing their disappointment that the meeting had been postponed and requesting their reinstatement. He emphasized that climate change meant that existing conservation instruments did require review, but that this did not mean that the current Directives were inappropriate. Flexibility was the key, as was adequate funding and an appropriate scientific base. It was essential that the biodiversity aspects of climate change were fully considered by responses in other sectors.

Plenary session

Colin Galbraith, Director of Scientific and Advisory Services, Scottish Natura Heritage, thanked the Minister for the speech and discussion that would prove invaluable to the discussions later in the day. He then introduced Nicholas Hanley, Head of Unit, European Commission and Des Thompson, Scottish Natura Heritage, to further set the scene for this important debate.

Nicholas Hanley, of the European Commission, addressed the possible mitigating and adaptive actions to combat climate change. Developing renewable energy sources (wind farms, biomass) presented both threats and opportunities. Adaptive measures (flood protection, strategic retreat) could create new habitats. Although existing measures such as the Natura 2000 network guaranteed wildlife refuges, these may not be large enough nor provide sufficient connectivity. Solutions could be non-legislative guidelines and a forum to discuss best practice. Agri-environment schemes could be extended and further measures would be needed to protect the native, non-migratory species most at risk from climate change. He concluded that further research was needed with integrated policies created through partnerships.

Des Thompson, Scottish Natural Heritage, discussed the possible adaptations to the loss of habitats and species, the threat of invasive species and non-linear changes to biodiversity (e.g. disease, eutrophication). His recommendations were to plan, to enable capacity for change and to identify which forms of management are realistic. Possible situations can come from changing climate states (e.g. recovering coastal ecosystems by planned flooding). The fragmentation problem can be overcome by ensuring there is a network of existing habitats that can result in a 5% increase in biodiversity. Various policies are in place to support these changes, such as Article 10, Water Framework Directive and the CBD. All sectors are responsible but we must be imaginative and advocate change.

Sue Collins, Director of English Nature, presented the conclusions of the European Environment and Sustainable Development Advisory Council (EEAC) and urged all Member States without an independent advisory council to consider creating one. 20 Councils from 13 countries produced the key EEAC message that mitigation an adaptation measures were needed to reduce the risks to biodiversity from climate change. Recommendations were to be made both the EU and the Member States and the EEAC suggested setting up a task force to gather together relevant information and to support the development of adaptive strategies. EEAC keenly awaited the Commission's communication as well as the Marine Thematic Strategy, which was hoped could provide binding legislation to meet the Gothenburg and Johannesburg targets. The Conference had concluded that raising the awareness of the public and politicians about the importance of biodiversity, the likely effects of climate change and the need for adaptive strategies was vital. Member States were urged to go beyond 2010 and not only halt the loss of biodiversity but also recover it.

Horst Korn, Chairman of the EPBRS Steering Committee, relayed the main focus of the EPBRS – that research must contribute to haling the loss of biodiversity. The main results were presented to the Nature Directors in a recommendation paper. This paper identified that research needs to identify the impacts of climate change on species, to further understand socio-economic aspects, to explore the interaction between biodiversity and adaptation in other sectors and to provide adaptation policy advice. Knowledge transfer was also a high priority from scientists to policy makers and vice versa.

<u>Workshops – Addressing the issues</u>

Workshop 1 – Climate change "proofing" of community policies
(Chair – Nicholas Hanley)
Key policy areas were identified where an interface between climate implications and biodiversity interests could be identified.

- Agriculture
    - Threats – exotic species, loss of marginal land on high biodiversity areas, fragmentation through intensification, increase in agricultural chemicals.

- Opportunities – Various approaches to the process of change, community institutions needed to be proactive in foreseeing likely future trends and responding accordingly.

- Water management
    - Threats – increased flooding and water shortages
    - Opportunities – the Water Framework Directive needs to respond to all future issues, re-establishing natural water cycles is critically important as an alternative to hard engineering solutions.

- Energy
    - Threats - increased hydroelectric power in wetland areas, uncontrolled push for wind energy
    - Opportunities – the biodiversity community must accept the legitimacy of renewable sources and create a positive, planned approach

- Coastal and marine
    - Threats – unsustainable practices will be aggravated by climate change
    - Opportunities – a structures response will require a more integrated approach to marine conservation on an ecosystem level as opposed to a narrow focus on fish stocks

Workshop 2 – Research priorities – ensuring use of existing knowledge, filling the gaps
(Chair – Miles Parker)
Research priorities were identified as follows:

- Effective adaptation strategies need to be evidence-based;
- EPBRS recommendations (see website for link) are welcomed, recognising that the scale of the effort required will need increased resources, but these are small relative to eventual costs to society;
- Note and support the research priorities outlined by EPBRS – building ecosystem resilience strategies that incorporate connectivity, increased socio-economic research to focus on ecosystem goods and services, adaptation research that is coherent with actions in other sectors (i.e. biomass research);
- Improve knowledge transfer, include participatory approaches (sharing best practice and lessons learned) and improve science-society interface;
- Call on scientific community to give best professional judgement based on available scientific evidence to enable urgent action;
- Implement adaptive management regime to ensure rapid feedback and continuous update.

Workshop 3 – Communicating the issue
(Chair – Mike Foulis)

Communication is important in democracy, in particular:-

- Three important audiences – practitioners, public and politicians – requiring appropriate communications and communicators;
- Clear communication – each country to adapt to own situation;

- Attitude of “nature people” can be a problem in delivering the solution;
- Need to have messengers in other sectors;
- What we should communicate is the bigger picture – an ecosystem approach, focussing on wider picture (not only the protected sites) and the longer term, not the minutiae.

Workshop 4 – Planning for change – How can Community mechanisms be used?
(Chair – Tamas Marghescu)

- FCS chapeau allows and encourages flexibility in the Habitats and Birds Directives, but the current application does not make use of this flexibility;
- Biodiversity protection must include broad ecosystem/landscape management as the foundation for sustainable development;
- Sectoral application of nature protection, including in the water environment, should be ensured to meet these challenges;
- The Nature Directors network provides an opportunity to share and develop innovative strategic ways forward, especially through cooperation with business and private sectors. Further discussion is necessary;
- All Community mechanisms, including Structural Funds, must address the needs of climate change. Money needs to be set aside for sectoral integration.

Discussion

Workshop 1

Colin Galbraith asked for suggestions on how goals would be achieved. Nicholas Hanley suggested each Member State outlined its pressures as soon as possible and that biodiversity discussions could be linked to the Kyoto requirements. He states that scenarios for adapting to climate change were not always complementary to biodiversity conservation (e.g. reliance upon transport for ecotourism).

Workshop 2

The Netherlands suggested that research should be focussed upon other sectors and financial issues. Miles Parker agreed that discussions should stress the goods and services of ecosystems and add financial aspects to biodiversity. Any framework should be initiated in partnership with other sectors and not in isolation.

The EEA proposed that the biodiversity and climate change communities came together since a lack of vision in biodiversity required a radically different approach. Miles Parkers recommended that resources should be made available within the Seventh Framework Programme for Research and Development for larger-scale research on the issue at an EU international level. Although EPBRS recognised the need for long-term research, policy-makers would need advice in the short-term. Research should be at the ecosystem level with integration of specialisations.

Finland argued that there was insufficient scientific knowledge about climate change in the EU, particularly for biogeographic zones. The Chair agreed that any framework initiative would need to work at ground level.

Workshop 3

The Commission asked how problems had arisen given the apparent support from practitioners, politicians and the public. Mike Foulis replied that biodiversity should be integrated into other structures, such as industry and farming policies in the Netherlands, and alternative opinions should be seen as valid.

France suggested that issues could be communicated in such as way as to not alienate the industrial sector. This highlighted the importance of choosing the appropriate language within the argument.

Denmark emphasized the need to educate future generations to explain the problems of biodiversity conservation. Mike Foulis replied that eco-schools were proving to be successful in engaging children with a hands-on approach to the environment.

Germany added the importance of discussing communication between Member States and supported the idea of creating a task force to deal with biodiversity conservation. Germany will develop a policy concept on nature conservation and climate change until 2008.

Workshop 4

Sue Collins supported the idea of a Nature Directors' forum if it produced a strengthened network. Tamas Marghescu suggested that it would require an organiser and that IUCN would be interested in providing assistance through its membership network. However, he proposed that the Commission had developed an inappropriate model for sustainable development and that natural resources needed to be the foundation where economy could be sustainable.

Conclusions

Colin Galbraith thanked all speakers and delegates before concluding that:-

- Awareness needs to be raised beyond Nature Directors' meeting
- Discussions have focused on how to take these issues forward
- Research should be prioritised at a higher level and integrated between countries
- Flexibility is necessary in all approaches
- Communication is crucial to disseminating the messages
- Time should be devoted to forming ideas and planning
- Task groups are required to direct the planned actions
- Opportunities will need to be taken pro-actively.

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