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CONVENTION ON THE CONSERVATION OF EUROPEAN WILDLIFE
AND NATURAL HABITATS

Conserving European biodiversity in the context of climate change

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"Climate change is one of the greatest threats that we are facing today – not just an environmental threat, but a threat to our economies, our way of life, perhaps even to our security and safety"

EU Environment Commissioner Stavros Dimas
Environment for European, No. 21 supplement, page 3
September 2005

1. Introduction: overview of climate change

It is an undeniable fact that the concentration of carbon dioxide (CO_2) in the atmosphere has been increasing. For much of the second millennium the concentration was about 280 parts per million (ppm). However, a little under 200 years ago, at the time of the "Industrial Revolution" in Europe, the concentration started to increase. During a period of about 150 years, it increased by 50 ppm to 330 ppm. The last 30 years have seen a similar increase, so that the concentration is now of the order of 380 ppm (Pearce, 2004). The historical and present concentrations of CO_2 in the atmosphere are undisputed facts; the only uncertainty being how steeply the CO_2 concentration will increase in the future (and such predictions depend upon the model being used and its underlying assumptions).

Interpretation of what the increasing CO_2 concentration in the atmosphere means for the climate of the Earth has not always been generally accepted. However, there is a considerable scientific consensus that CO_2, together with a number of other gases such as methane (CH_4), acts as a "greenhouse gas", allowing the atmosphere of the planet to absorb and retain more of the solar energy received by the Earth. Many models have been developed in order to study various scenarios of change. It is not the role of this paper to review either the models or their associated predictions of change. It is, however, the aim of this paper to explore what the predicted changes might mean for Europe's biodiversity and for the legislative and practical aspects of conserving Europe's natural heritage.

A very considerable majority of scientists accept that the increasing CO_2 concentration in the atmosphere (as well as other chemicals released into the atmosphere) will cause a substantial and rapid change in the climate of the Earth. This will be manifest in many ways, some of which are

- a substantial increase in average temperature,
- a change in patterns of precipitation, with some areas becoming significantly wetter whilst other areas will become drier,
- an increased average wind speed,
- an increase in the frequency of extreme events (e.g. droughts and storms),
- shrinking of the ice caps in the Arctic and the Antarctic,
- a rise in sea levels,
- thinning of the Earth's protective ozone layer, leading to increased amounts of the damaging ultraviolet (UV-B) radiation, and
- in the longer term, a change in the ocean's currents (i.e. some models indicate that the North Atlantic Drift might stop, which paradoxically would cause much of western Europe to become colder).

Each of these changes will affect Europe and there is increasing European concern about the consequences of climate change [as for example the articles "Wake up to climate change" (*Environment for Europeans*, No. 17, page 7, September 2004) and "Grasping the climate change challenge" (*Environment of Europeans*, supplement to No. 17, page 11, September 2004)]. One effect of climate change will be on Europe's biodiversity, on its land, in its fresh water and in its sea. It is useful to put climate change into an international perspective: the United Nation's Convention on Biological Diversity and the European instruments of the Bern Convention, the Bonn Convention, and the European Union's Birds and Habitats Directives (the "Natura 2000 Network" of protected areas and the associated network outside the EU known as the "Emerald Network").

The paper does not attempt to provide a full review of the subject. On the internet, if one enters the two words "climate change" into Google, it responds with about 113,000,000 results (mid-October 2005). The words "nature conservation" yield about 43,100,000 results, the one word "biodiversity" about 36,300,000 results, and the three words "climate change biodiversity" about 8,870,000 results. With this amount of information available, a full review would obviously be a lengthy document! However, one key aspect of current climate change that has major implications for biodiversity is its rate and scale. If CO_2 emissions are not tackled as a matter of global urgency, the 21st Century is likely to experience a change in climate similar to the ending of the last major ice age, about 10,000 years ago. However, the projected changes will be over a time scale that is an order of magnitude shorter, and this will not be within the evolutionary experience of species; it will also be against a landscape that has been greatly modified by human activity.

There are three approaches to climate change, namely

- mitigation of the forces driving climate change,
- adaptation to the effects of climate change, and
- engagement of the public in understanding and addressing climate change.

This paper addresses issues of 'adaptation', but in narrowing down its scope this does not mean that the engagement of the people of Europe, nor the political imperatives of encouraging mitigation, are any less important. To conserve Europe's biodiversity, all three approaches are necessary.

This paper therefore provides an initial starting point for discussion about possible adaptation strategies if Europe's biodiversity is to be conserved. Whilst there is uncertainty about both the timing and magnitude of changes, such uncertainties should not militate against action being taken now, either by individual nations or, preferably, internationally. However, as with the international collaboration in the Arctic, culminating in the *Arctic Climate Impact Assessment* (ACIA – see www.acia.uaf.edu), there would be merit in a larger scale pan-European scientific study of the effects of climate change on all aspects of Europe's environment (encompassing biodiversity as well as human society, economy and health).

2. International aspects of nature conservation

Within Europe there is a long history of legislation that has aimed to protect wildlife. Perhaps the first Act of a European Parliament was the Sea Birds Protection Act 1869 in the United Kingdom (Sheail, 1998). During the next century there are innumerable Acts in European legislatures focussing increasingly on broader aspects of nature conservation. One of the earliest Europe-wide instruments was the "Convention on the Conservation of European Wildlife and Natural Habitats" (the Bern Convention) of 1979, which came into force on 1 June 1982. It sparked a flurry of national activity in order to transpose it into the wide variety of national legislations. International aspects of nature conservation were further stimulated by the Bonn Convention, which deals with migratory species.

The European Union has also been active in developing the Bern Convention. The first major instrument was the Birds Directive of 1979 that, *inter alia*, made provision for a network of Special Protection Areas (SPAs). This Directive was taxonomically limited to species of birds. The second major instrument was the Habitats Directive of 1992, which extended to concept of conserving species to all other taxonomic groups (outlined largely in Appendices I to III of the Bern Convention) and developed the concept of habitat conservation. Again, *inter alia*, it makes provision for a network of Special Areas of Conservation (SACs) throughout the member states of the EU. Both of these Directives require Member States to take action in the wider environment, complementary to the site-based approach of protected areas, so as to achieve favourable conservation status for the listed species and habitats.

Through the auspices of the United Nations, moves were also afoot to develop an international convention. This was agreed at a conference in Rio de Janeiro, Brazil, in 1992. All signatories of the Convention on Biological Diversity (CBD) are obliged to support the objectives, which are "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources …" (CBD, 2000). The CBD is not as prescriptive as the EU's Directives (i.e. it does not require networks of protected areas to be designated or classified), but nevertheless all Contracting Parties are expected to develop strategies, plans or programmes for the conservation and sustainable use of ecosystems, habitats, species, and described genomes and genes (Article 6 and Annex 1 of the CBD).

This brief review omits many other international agreements that influence European nature conservation – for example the Ramsar Convention (for wetlands) or the Circumpolar Protected Area Network (for the Arctic). However, the review demonstrates that, to be effective in the long-term, actions to conserve habitats, communities, species and genes need to consider the possible (or likely) effects of climate change. These changes are considered in the following section (section 3), and some possible responses are outlined in section 4. To be effective, it is insufficient to identify the potential problems caused by a rapidly changing climate; knowledge of these problems has to be translated into international and national policies, implemented in international and national legislative instruments, and actions will need to be carried out on the ground, and in the seas and fresh waters, of Europe. This paper is not concerned with the major global actions to limit and control climate change (e.g. the Kyoto Protocol), but rather to deal with the implications of a changing climate for Europe's biodiversity.

3. Anticipated changes in Europe

3.1. Overview

Eight separate topics have been chosen for discussion in this section. Such an approach highlights the main effects that climate change might have on Europe's biodiversity, but it unfortunately makes such effects appear very discrete and easily separable one from another. In reality many of these eight aspects of the effects of climate change may be occurring simultaneously, possibly together with other changes not discussed here, and so there will be many interactions. Thus, the effects of climate change need to be considered in as holistic a manner as possible.

A note also needs to be added about the terminology that has been used. In the following sections the focus is generally on "plant communities", generally shortened to "communities". However, in many instances this can be synonymised with the word "habitats". For example, the various habitats listed in the first appendix of the EU's Habitats Directive are almost entirely defined in terms of the plant community, its dominant species, and the variants that occur in relation to the geographical distribution of some of its characteristic species (cf. the explanation of the habitats in European Commission, 1996). Whereas in the terrestrial environment plants are often used to define habitats, in the marine environment it is the animal communities and the physical structure of the substrate (e.g. rock, sand, mud) that is used to define habitats. In section 3 the word "community" will be used, whereas in section 4 the word "habitat" will be used.

There has been a number of reviews of the effects of climate change on biodiversity. For example, CBD (2003) analysed the inter-relationships with particular reference to the United Nations Framework Convention on Climate Change (UNFCCC). The effects on Europe's ecosystems and various forms of land use were considered by both Parry (2000) and Green (2001). More regionally, Hossell *et al.* (2000) reviewed the implications of climate change for nature conservation policy in the United Kingdom, whereas narrower and more taxonomically limited studies have been undertaken on seabed wildlife (Hiscock *et al.*, 2001) and farmland birds (Anon., 2000).

3.2. Geographical range of plant communities

In a warming environment it can generally be assumed that the geographical range of a community will move northwards and locally that it will move uphill. Although such a generalisation may be largely true, it hides huge differences between communities, both in how far they will move and in whether or not they are actually able to move. Communities, being composed of individual species, will each react to a changing climate in an individualistic way.

A good example of modelling to determine this shift in "climate-space" is the predicted movement of blaeberry (*Vaccinium myrtillus*) heaths in Norway. As well as a northward movement, they are predicted to move uphill with the mean altitude changing from about 760m to 1160m (Holten & Carey, 1992). The critical questions for the protection of such heath are whether all of the heaths below, say, 700m will cease to exist, how quickly this will happen, and whether heaths can actually establish themselves at altitudes of, say, between 1300 and 1600m.

Another example is the modelling of the changes in the treeline, dominated by the dwarf mountain pine (*Pinus mugo*), in the Austrian Alps (Dullinger *et al.*, 2004). They predicted that, over the next 1000 years, the area covered by pines in their study landscape would increase from the current 10% to between 24 and 59%. Although it will be difficult to prove that such predicted changes will actually occur, it is supported by evidence from Canada that indicates that stunted black spruce (*Picea mariana*) on the treeline (known as "spruce krummholz") has grown out into more erect forms with the increase in temperature during the 1990s (Gamache & Payette, 2004)

Models used to predict the eventual distribution of communities generally rely on identifying the climate-space occupied by the contemporary community, and then identifying where the community's climate-space will occur under the various scenarios of climate change. It is much more difficult to identify if any communities have actually moved, and hence observational information is almost totally lacking; four reasons can be quoted for this. One reason is that plant communities are generally poorly defined. Even with the example of the *Vaccinium* heath quoted above, how much *Vaccinium* would have to be lost from the plant community before the habitat could no longer be classified as such a heath, and equally how much *Vaccinium* would the receiving area have to acquire before that could be so classified? In reality, this reason is that natural and semi-natural plant communities are continua, merging from one type into another. A second reason relates to the length of time that is required to observe a movement of a community; responses are unlikely to be rapid, especially for communities dominated by long-lived trees and shrubs. A third reason relates to the fragmentation of so much of Europe's environment, partly by land use and partly by the creation of barrier such as roads and dams. How can a habitat move if there are barriers to movement such as agricultural land or commercial forests of non-native trees? Similarly, a fourth reason might be natural barriers to movement, such as mountain ranges or water barriers.

3.3. Geographical range of species

Much more is known about the likely changes in the distribution of species with a changing climate. A poleward extension is predicted for many of the fish species of the northern Atlantic, including the herring (*Clupea harengus*), cod (*Gadus morhua*) and some of the flatfish that are currently limited by bottom temperatures. At the same time the southern limits of colder-water fish species, such as polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*), are expected to move northwards. The latter species tend to migrate so as to follow the southern limit of the Arctic ice cap, and as this recedes northwards these species are shifting their geographical distributions (Hassol, 2004). Complexity arising from alterations to the density, distribution and/or abundance of keystone species at various trophic levels, such as the polar cod or the polar bear (*Ursus maritimus*), could have significant and rapid consequences for the structure of the ecosystems in which they currently occur.

As with communities, it is "climate-space" that is often used in developing predictive models. Such models make the assumption that the species currently occupies its optimal climate-space and also that the species will be able to move as the climate-space changes its geographical range. These assumptions beg many questions about the suitability of areas to move through, and the lack of barriers to movement such as mountains for terrestrial species and the problems of moving from lake to lake or from river to river for freshwater species. In some instances, the climate-space appears to vanish. An example of this is Dockerty *et al.*'s (2003) prediction that the relict Arctic and Boreo-Arctic montane species that occur in the temperate regions of Europe are all likely to have a reduced probability of occurrence in the future. Predictions are, however, surrounded by uncertainties, because of the assumptions implicit in the models and often because of lack of experimental data about the individual species (Higgins *et al.*, 2003).

There is increasing observational evidence that changes are already occurring. In a study of non-migratory European butterflies, Parmesan *et al.* (1999) analysed the distributions of 35 species, in 6 families, with data from Algeria, Estonia, Finland, France, Great Britain, Morocco, Spain, Sweden and Tunisia. They found that, during the 20th century, 22 species demonstrated a northward shift in their geographical distribution, whereas only two species had a southward shift (11 species showed no shift in distribution). Such shifts occur either because of a net extinction at the southern boundary of the distribution or because of a net colonization at the northern boundary (or both). Similarly for 51 species of British butterflies, Hill *et al.* (2002) found that 11 of 46 species with a southerly distribution have expanded in the northern part of their distributional range. The few species with a northern and/or montane distribution have largely disappeared from low altitude sites, but during the 20th century they have colonised higher elevations. Evidence from the USA (Crozier, 2004) suggests that increasing winter temperatures may also be driving the northwards expansion of butterfly species.

It is perhaps amongst the invertebrates that there is most evidence of the effects of climate change, largely because they are to some extent mobile and because of their annual generations. The greatest amount of observational data exists for the Lepidoptera. However, there is increasingly a worldwide series of examples of poleward shift for many other invertebrate groups such as the dragonflies and damselflies (Odonata), spittlebugs (Hemiptera) and beetles (Coleoptera). Their life histories allow them to respond more rapidly to climate change, but the message that continually comes from these observational studies is that not all species respond in the same way. Each species has its own response, and it is understanding this range of responses that will be essential for the conservation of species richness as the climate changes.

The individualistic responses of species may produce some novel effects. Take a simple, hypothetical example of a community currently characterised by broadly similar abundances of three species, A, B and C (Usher *et al.*, 2005), defined as community ABC. Under a climate change scenario with species moving northwards, suppose species A is able to move rapidly, that species B moves more slowly, and that species C hardly moves at all. This might mean that in the future there could be a community dominated by species A with species B as a sub-dominant (community Ab) in the north, as well as a community dominated by species C also with species B as a sub-dominant (community bC) more or less geographically where ABC used to occur. It is possible that neither Ab nor bC are currently recognised as communities, and hence in the geographical contraction of ABC at least two new communities – Ab and bC – have arisen, both of which are novel. What would happen in the intervening area, where B might be dominant – would there be an aBc type community? The differential responses of species to climate change might give rise to many new community types, defined on the basis of their dominant or characteristic species, and hence although species richness might not be reduced, it is possible that community (habitat) richness might be increased.

3.4. Extent of communities

The extent of communities will be dependent upon the individualistic responses of the component species, and these in turn will be dependent upon the physiological responses of the individuals that form those species populations. In the marine environment, rather little is known about the potential effects of warmer water temperatures, acidification due to increased absorption of CO_2 or increased irradiance by UV-B. However, change can be very speedy, as demonstrated by the comparison of marine nature reserves with undesignated areas by Halpern & Warner (2002) – the average values of density, biomass, organism size and species diversity all increased within 1 to 3 years of designation and protection. These rapid responses suggest that marine communities might respond very quickly to changed environmental conditions.

In terrestrial environments the extent of a community will depend upon the balance between the speed with which areas of the community disappear in some parts of its range and the speed with which the community is able to colonise new areas. Holten & Carey (1992) modelled Norway spruce (*Picea abies*) forest in the north of Europe. At the present time it occurs throughout Fennoscandia and Russia, more or less as far north as the shore of the Arctic Ocean. The model indicated that if the winter temperature rose by 4^{o}C, the geographical range of the spruce forest virtually halves. The majority of the southern and south-western populations would disappear. The spruce would not have been able to colonise northwards because of the barrier of the Arctic Ocean, and hence its distribution is squeezed into a smaller area. This clearly has implications for the many species of animals, non-vascular plants, lichens and fungi that are associated with European spruce forests. Conversely, beech (*Fagus sylvatica*) forest, with a more southern distribution, is predicted to expand northwards, and might even colonise coastal areas near the Arctic Ocean. There appear to be no barriers to its movement, and hence the extent of beech forest is likely to expand. This again has implications for the species associated with European beech forests.

There are five groups of communities that seem to be particularly prone to reduction in extent as a result of climatic warming.

- Any community for which there is a physical barrier to halt its movement northwards. The main barriers fall into two classes. One would be the Mediterranean Sea, the Arctic Ocean, and possibly other European seas such as the North Sea and English Channel. The other would be mountain ranges, especially those running from east to west, such as the Alps from France through Switzerland into Austria, the Pyrenees to the north of Spain, and the Carpathians from the Czech Republic, through Slovakia and Ukraine into Romania.
- Alpine and upland habitats, those above the treeline, where the climate-space will be reduced by its shift in altitude. Although some new ground for colonisation will become available as a result of previously permanent ice thawing (Nagy *et al.*, 2003), it is likely that the extent of many of the alpine heaths and open ground communities will decrease. The review by Robert Björk ('Ecology of alpine snowbeds and the impact of global change', unpublished, University of Göteborg) in Sweden has demonstrated the particular vulnerability of snowbeds to climate change. Whereas they provide nutrients and water to the surrounding plants communities (and to herbivores) late in the growing season, they are likely to become invaded by neighbouring shrubs and boreal species. The ecosystem services that they provide will thus either decline or disappear.
- With sea level rise there will be a compression of the coastal zone. This will reduce the extent of salt marshes and sand dune systems, and on the extreme western fringes of Europe the machair will be squeezed between the sea and the higher ground. Coupled with a greater frequency of storms, this is likely to have considerable effects on all coastal communities, as demonstrated for the North Sea coast of The Netherlands and Germany and along the Baltic coast (Irmler, 2002). Muir (2005) sees sea level rise as a major threat to Europe's coastal and maritime biodiversity.

- Wetlands pose considerable problems. With predicted warming, leading to potentially greater evaporation, and predicted decreases in precipitation in much of Europe, many wetlands could dry up. This could affect the communities of peatlands, fens, shallow lakes and ponds.
- Marine communities: as well as temperature effects, there have been recent suggestions that the increased CO_2 being absorbed by the sea, and hence acidification of the sea water, could affect many species, disrupting marine food webs and altering ocean biogeochemistry.

3.5. Abundance of species

The individualistic responses of the species (Oswald *et al.*, 2003) will depend upon the dynamics of the species populations, the competitive or mutualistic interactions between species, and the biochemical and physiological responses of the individuals. The latter are fundamental aspects of how an individual will respond both to its environment and to changes in that environment. For example, Rey & Jarvis (1997) demonstrated that young birch (*Betula pendula*) trees grown in an atmosphere with elevated CO_2 had 58 per cent more biomass than trees grown in ambient CO_2 concentrations. They also found that the mycorrhizal fungi associated with the roots of these experimental trees differed; those grown in elevated levels of CO_2 were late successional species, whereas those grown in ambient CO_2 levels were the early successional species. This demonstrates the complexity of understanding the effects of climate change on the conservation of biodiversity. Normally, with regenerating birch trees, one would expect the whole successional suite of fungi to be present on the young trees' roots as they emerge from the seed, establish themselves, grow and then mature. Do Rey & Jarvis' (1997) results imply that considerably more attention needs to be given to protecting the early successional mycorrhizal species? Such species will clearly be needed in the ecosystem if the climate cools again or if CO_2 levels fall sometime in the future. This also underlines the importance of understanding the effects of climate change on the biota in the soil, essential for Europe’s major land uses of agriculture and forestry.

Other physiological studies have detected a 4 to 9 per cent thickening of the leaves of the lingonberry (*Vaccinium vitis-idaea*) under enhanced ultraviolet-B (UV-B) radiation, whereas the deciduous blaeberry and bog blaeberry (*V. uliginosum*) both had 4 to 10 per cent thinner leaves under similarly enhanced UV-B (Björn *et al.*, 1997). The growth of the moss *Hylocommium splendens* was strongly stimulated by enhanced UV-B, provided that there was additional water, whereas the longitudinal growth of the moss *Sphagnum fuscum* was reduced by about 20 per cent. Björn *et al.* concluded "it is currently impossible to generalise from these data". This is supported by Beier's (2004) comment that "the few examples of combinations of CO_2 and warming point in all directions and results are not predictable based on individual effects".

Björn *et al.* (1997) did not experiment with the effects on invertebrate animals, especially moth larvae. These, notably those in family Geometridae (the "loopers" or "spanworms"), form a large component of the food of many passerine birds in the boreal forests. If the population densities of these larvae were reduced due to a lack of palatability of the leaves on which they feed, the effects of UV-B could be far-reaching on both the below- and above-ground food webs of the terrestrial Arctic and Boreal communities in Europe.

In the marine environment, seabirds show strong preferences for regions of particular sea surface temperatures (SSTs) (Schreiber, 2002). Guillemot (*Uria aalge)* populations tended to increase where SST changes were small; conversely, but they tended to decrease where SST changes were large. Although this species breeds throughout the circumpolar north from the high Arctic to temperate regions, it is the dominant species in the southern part of this range (Gaston & Jones, 1998). The highest rate of increase occurred where SST changes were slightly negative, whereas increases for the Arctic-adapted Brunnich's guillemot (*Uria lomvia*) were most rapid where SST changes were slightly positive. These results demonstrate that seabirds are likely to respond to changes over large temporal and geographic scales. Without detailed knowledge of each species, and the inclusion of such data in predictive models, it is difficult to predict which species will become more abundant with climate warming, and which are likely to decline.

This implies that there are seven categories of species that are particularly susceptible to climate change (IUCN, 2003). They are

- species with bounded distributions, such as mountain tops, low-lying islands, and high latitudes and those at the edges of continents;
- species with restricted geographical ranges;
- species with poor dispersal capability relative to the projected nearest suitable climate space (e.g. due to physical barriers such as mountain ranges or fragmented landscapes, or due to the species own attributes such as flightlessness);
- species that are particularly susceptible to extreme (high or low) temperatures, drought, snowfall, sea surface temperature, flood, etc.;
- species that have extreme habitat/niche specialisation such as a narrow tolerance to climate-sensitive variables;
- species that have evolved a close or synchronous relationship with another species; and
- species that have inflexible physiological responses to climatic variables.

3.6. Phenology

"Phenology" is defined in the *New Oxford Dictionary of English* as "the study of cyclic and seasonal natural phenomena, especially in relation to climate and plant and animal life". More specifically, it usually relates to the time in the year when a particular life history event happens, such as when the eggs of an insect species hatch into larvae, when a vascular plant sets its seeds, or when migratory birds arrive back in the spring.

There is growing evidence that the phenology of many species is changing. For example, the detailed study of 217 vascular plant species between 1978 and 2001 in southern Scotland demonstrated that the first flowering date of many species advanced with increasing temperatures (over the 24 year period the temperature rose on average by $0.3^{o}C$ per decade). January or February temperatures particularly influenced species that flowered early in the year, whereas those flowering later in the year were affected by temperatures between March and July (Roberts *et al*, 2002). Correlations between onset of flowering and environmental factors other than temperature, such as rainfall, demonstrated few statistically significant relationships. The same study also indicated that frog spawning advanced with warming air temperatures in the early part of the year.

Another study using part of the same data set (Last *et al.*, 2003) indicated an almost linear relationship between advancement or retardation of flowering and the mean date of onset of flowering. Thus, using 27 native species, those flowering in late February (about day 50 in the year) were advancing by about 1.35 days per year over the 24 year period (i.e. by about a month in total), whereas those flowering at the end of May (about day 150) had only advanced by about 0.4 of a day per year and those flowering in August (about day 220) were retarded by a similar amount. This may be related to the increasing length of the growing season, which is likely to be more pronounced in northern Europe than in southern Europe.

Similar results have been obtained for the date of onset of flowering for a number of garden plant species in England (Hepper, 2003) and for the blaeberry (*V. myrtillus*) in Finland (Heikinheimo & Lappalainen, 1992). Similar trends have also been demonstrated for the bud burst of tree species in Germany (Badeck *et al.*, 2004). However, in all of these studies, except for the Finnish one that focussed on only one species, the results show that the species behave differently. Thus, in Last *et al.*'s (2003) study, although the mean advancement of late May flowering plants was 0.4 days per year, this encompassed a range from about an advancement of 0.9 days per year to a retardation of 0.4 days per year. Again, the implication is that there is no norm but that the individual species behave individualistically.

Many other changes in phenology have been noted (Mackey *et al.*, 2001). These include the earlier arrival of migratory birds in spring, earlier laying of the first egg in the first clutch of some species of birds, and the earlier first flight of a number of butterfly species. Again, different species within a taxonomic group react differently to the increasing temperature so that it is impossible to make predictions if there are no observational data. However, this wealth of studies draws attention to two further important points for the conservation of Europe's biodiversity.

First, virtually all observations are at the start of the year, in the spring. There are very few observations at the end of the year, i.e. when migratory birds leave or when flowering stops, although there is an apparently increasing frequency for butterflies to have a second generation. Whereas the monitoring appears to be reasonable for springtime activities, it is still poor for autumnal activities.

Second, we need far more information on the interactions between species. For example, predators or parasites and their prey, or herbivores and their plant hosts, tend to be synchronised, and there is already some suggestions that trophic levels are differentially sensitive to climate change (Voigt *et al.*, 2003). If one species in such an interaction changes its phenology faster than the other species, there is a risk that they will become unsynchronised. This could have serious implications, both unforeseen and unpredictable, for biodiversity conservation.

3.7. Genetic diversity

It is surprising that so little attention had been paid to the effects of climate change on genetic diversity, especially as it is included as one of the major themes in the *Convention on Biological Diversity*. Looking at the large books on global biodiversity, Groombridge's (1992) account contained 241 pages devoted to species diversity, 80 pages on the diversity of habitats, but only 6 pages on genetic diversity. Similarly, Heywood's (1995) *Global Biodiversity Assessment* contained only 32 pages addressing this subject amongst its 1140 pages.

The reason for this discrepancy is obvious. Species tend to be tangible entities and many of them are easily recognisable. The species concept does not work well, however, for many of the single-celled forms of life, often living in soils or sediments under fresh water or the sea, where the genetic variability is often more important than the identity of the species themselves. Genetic variability is often not visually recognisable and can only be detected with sophisticated methods of analysis using modern molecular techniques. Of the millions of species that exist on Earth, very little is known about their genetic diversity except for a few species that are of economic importance, a few species that are parasites of people or their domestic stock, and a few other species that geneticists have favoured for their research (such as the *Drosophila* flies).

What then can be done to conserve Europe's genetic diversity in a changing climate? Assuming that natural selection requires genetic diversity for it to operate, conservation practice should aim to find a surrogate for the almost unknown genetic diversity. This can best be done by conserving each species over as wide a geographic range as possible and in as many habitats as possible, on the assumption that geographical and environmental features have structured genetic variation. Throughout continental Europe, a continuous postglacial range expansion is assumed for many terrestrial plant and animal species. This has often led to a population structure in which genetic diversity decreases with distance from the ancestral refugium population (Hewitt, 2000), and hence northern populations are often genetically less diverse than their southern counterparts (Hewitt, 1999). There are at least three features of genetic variability that need to be considered in the conservation of the Europe's biodiversity.

First, the genetic structure of a species at the edge of its range, where it is often fragmented into a number of small and relatively isolated populations, is often different from that in the centre of the range, where populations can be more contiguous and gene flow is likely to be greater. It is these isolated, edge-of-range populations that are possibly undergoing speciation, and which might form the basis of evolution towards different species with different ecologies in the future, but it is equally possible that these populations are those most threatened by climate change. Although unproven, is it these populations that have the genetic diversity that will enable the species to adapt to climate change?

Second, climate change might mean that hybridisation becomes more common; this can both be a threat and an opportunity. For example, it can be a threat where two species loose their distinctive identities, as is happening with the introduction of the Sika deer (*Cervus nippon*) from Japan into areas where the native red deer (*Cervus elaphus*) naturally occurs. There is a potential problem with the introduction into Europe of any non-native species that is biologically closely related to a native European species. Hybridisation can also be an opportunity, as with the hybrid between the European and American *Spartina* grasses (both species of mudflats in estuaries), which then doubled its number of chromosomes and now acts as a newly evolved species in its own right.

Third, there are suggestions (Luck *et al.*, 2003) that the genetic variability of populations is important in maintaining the full range of ecosystem services. Although this concept is little understood, it is intuitively plausible because, as factors in the environment change, individuals of differing genetic structure may be more or less able to fulfil that species' functional role in the ecosystem. Thus, with a changing environment, the ecosystem needs species whose individuals have a variable genetic make-up.

3.8. Behaviour of migratory species

Migration is often a cold and ice avoidance strategy used by birds, marine and terrestrial mammals and fish. For example, many species of shorebirds (or waders) nest in the Arctic in the spring and early summer, but in the late summer and autumn fly south to spend the winter in warmer climates. At least two of the world's eight major flyways involve Europe (Figure 1).

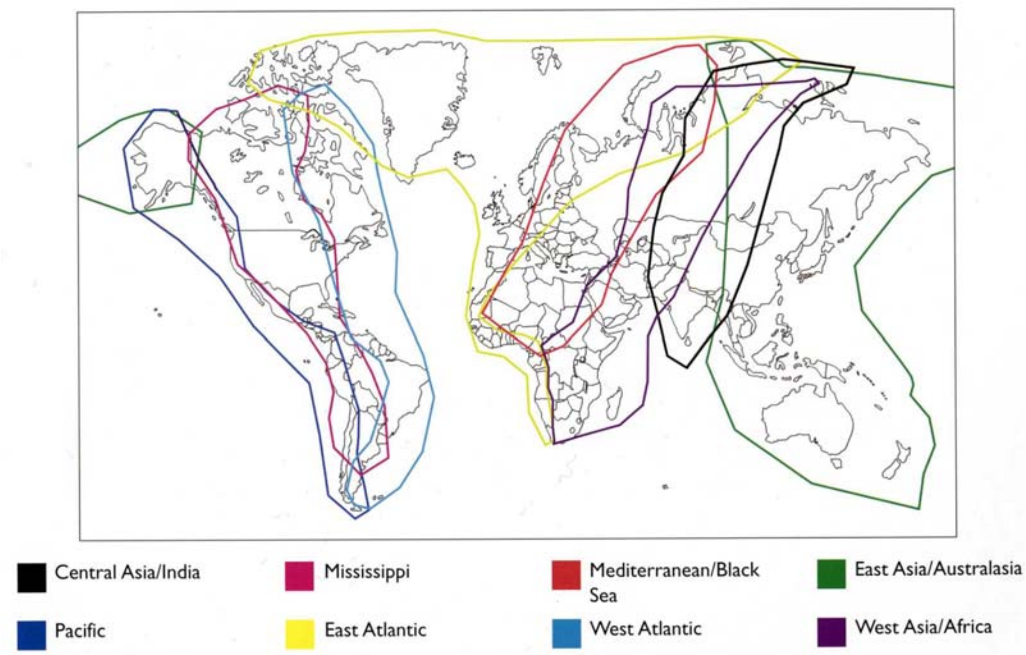

Figure 1. The eight major flyways used by shorebirds (waders) on migration. Two of these – the East Atlantic and the Mediterranean/Black Sea – involve birds spending a considerable time in Europe. From Thompson & Byrkjedal (2001).

These birds live in two major geographical areas, and in transit between these areas require other areas for resting and feeding. The goose species of the Western Palaearctic region provide good examples of migratory species that have been the subject of considerable research and conservation action (Madsen *et al.*, 1999). Sixteen populations of seven species (11 subspecies) nest in the Arctic and winter further south in Europe. The three populations of the barnacle goose (*Branta leucopsis*) can be used as an example.

The western population breeds near the coast along north east Greenland from about 70^o N to 78^o N. On the autumnal migration the geese stage in Iceland, near the south coast, where they spend about a month feeding before they fly on to the wintering grounds along the west coast of Ireland and the west and north coasts of Scotland. In the spring, the geese leave in April, and stage on the north west coast of Iceland for 3 or 4 weeks before flying back to Greenland to recommence the annual cycle. A second (or central) population breeds in Svalbard, between about 77^o N and 80^o N. After breeding, the geese leave Svalbard in August and many of them arrive on Bjørnøya at the end August and remain there until late September or early October, when they fly on to the Solway Firth in south western Scotland. They return north in the spring, staging in the Helgeland Archipelago off the coast of Norway (between 65^o N and 66^o N) for 2 to 3 weeks before flying on to Svalbard. The eastern population breeds in northern Russia, from the Kola Peninsula in the west to Novaya Zemlya and the Yugor Peninsula in the east. In the autumn the birds fly south west, along the Gulf of Bothnia and the southern part of the Baltic Sea, staging on the Estonian and Swedish Baltic islands. The majority of the birds winter on the North Sea coast of Denmark, Germany and the Netherlands.

This example demonstrates a number of features of migratory populations and their conservation in a changing environment. The geese require sufficient food resources to make two long journeys each year. The summer feeding grounds in the Arctic and the wintering feeding grounds in temperate Europe provide the majority of the geese's food requirements. However, whilst on migration, the geese need to stage and replenish their energy reserves. In years when winter closes in early and Bjørnøya is iced over before the geese arrive, it is known that many of them are unable to gain sufficient energy to fly on to Scotland and hence there can be a very heavy mortality, especially of the current year's young. Although the three populations appear from the brief descriptions given above to be geographically isolated from each other, there is a very small amount of mixing of birds between these populations, and hence gene flow is probably sufficient for this one species not to have sub-speciated.

Climate change could have an effect on these species. As habitats change, will the breeding grounds move northwards? This could be possible for the Greenland nesting population because there is land north of the current breeding range. It could hardly happen for the populations breeding on Svalbard and in Russia because there is very little ground north of the current breeding areas (just the north coast of Svalbard and the north of Novaya Zemlya). How will the wintering grounds change? Because many of these are managed as grasslands for cattle and sheep grazing, it is possible that there may be less change. However, the staging areas are also likely to change, and it is possible that the distance between breeding and wintering grounds might become longer, requiring more energy expenditure by the migrating birds. This leaves a whole series of unknowns, but at the present time these goose populations are increasing in size; will this continue as the climate changes?

3.9. Problems caused by non-native species

The topic of *biological invasions* has fascinated ecologists for well over half a century (Elton, 1958). More recently, the many problems caused by non-native species have become more apparent, and the IUCN (The World Conservation Union) puts them forward as the second most important reason for loss of the Earth's biodiversity (after the primary reason which is loss and fragmentation of habitats). A word of caution is, however, needed about the use of language. Why a species is geographically where it is currently found cannot always be determined; if it is known to be there naturally, it is generally referred to as being "native". If it is known to have been brought in from another geographical area by human agency, either intentionally or unintentionally, it is referred to as being "non-native" (Usher, 2000, discussed these distinctions and the gradations between them). The term "non-native" is essentially synonymous with "alien", "exotic" and "introduced", all of which appear in the literature.

Williamson (1996) described the "10:10 rule", whereby he suggested that 10% of species introduced to an area would establish themselves (i.e. they do not die out within a few years of introduction, and start to reproduce), and that 10% of these established species become "pests" (i.e. they become problematic is some way). Whereas this rule seems to be reasonably true for plants, it appears to underestimate the numbers of vertebrate animals that become problematic (Usher, 2002a). It is this 1% (10% of 10%) of species that are introduced, or rather more than 1% of vertebrate animal species, which can be termed "invasive". In Europe there is a number of non-native species that cause problems or potentially could become problematic.

In terrestrial ecosystems, climate change might mean that more species will be able to survive in the more northerly parts of Europe. It is an arguable point whether new species arriving can be classified as "native" or "non-native" when the rapidly changing climate is anthropogenically driven! However, with a changing climate species are likely to move northwards, and some of these will establish themselves by forming reproducing populations. Northern European countries might become more species rich because there is an ability of species to move northwards to colonise them. On the other hand, because of the east-west orientation of the Mediterranean Sea (and desert/arid areas south of this), there will be limited scope for southern European countries to gain new species by a northward movement. Taking Europe as a whole, this might imply that its species richness will change little, though that of the individual nation states might change substantially. At the country level, some of these newly established species may become problematic, but at the moment there are no means of determining the major risks. However, the introduction of disease organisms, for both wildlife and people, is a distinct possibility.

In the boreal forests, the insects, as a group, pose the most serious challenge because of their ability to increase rapidly in numbers and because of the scarcity of effective management tools. Based on past experience, it is reasonable to assume that many forest-damaging insects have the potential to appear at outbreak levels with a warmer climate and increased tree stress levels, even although they have never yet been observed to do so. Two examples will demonstrate the risks. First, the bronze birch borer (*Agrilus anxius*) has been identified as a species that can cause severe damage to paper birch (*Betula papyrifera*), and may be effective in limiting the birch along the southern margin of its distribution (Haak, 1996). Second, an outbreak of the Siberian silkworm (*Dendrolimus sibiricus*) in West Siberia from 1954 to 1957 caused extensive tree death over three million hectares of forests. Movement of outbreak levels of this species northward would considerably alter the dynamics of Siberian forests. Although neither of these examples in strictly European, there are a number of insects in Europe, such as the autumnal moth (*Epirrita autumnata*), that could defoliate large areas of forest.

In the freshwater environment, again there are similar concerns. It is the introduction of fish species that can cause most problems. For example, in Loch Lomond in Scotland the invasive ruffe (*Gymnocephalus cernuus*) eats the eggs of an Arctic relict species, the powan (*Coregonus lavaretus*), thereby threatening this species in one of its only British habitats (Doughty *et al.*, 2002). There are also potential problems with fish that escape from fish farms and enter the natural environment and breed with native fish stock. The genetic effects of such interbreeding can be profound, altering the behaviour of the resulting fish stock, as has been found with the Atlantic salmon (*Salmo salar*) in Norway.

In the marine environment one of the major potential problems is the discharge of ballast water. With thinning of the Arctic sea ice and the opening up of the Arctic Ocean to more shipping for more of the year (especially the prediction of the opening of the north-east passage between Europe and Asia), the possibility of the introduction of non-native species is greater and the environmental risks are increased. Analyses of ballast water have indicated that it can contain a large number of different species of marine organisms, including marine algae and molluscs that are potentially invasive. Regulation of discharges of ballast water in not easy to achieve, nor is its enforcement always possible, but to prevent the threat of invasive marine organisms it is essential that international agreements regulate such discharges in both coastal waters and on the high seas. The Global Ballast Water Management Programme (GloBallast) has an important role. Amongst its aims are (i) reducing the transfer of harmful aquatic organisms and pathogens in ships' ballast water, (ii) implementation of the International Maritime Organization's (IMO's) Ballast Water Guidelines, and (iii) assistance with the International Convention for the Control and Management of Ships Ballast Water & Sediments (see www.globallast.imo.org/index.asp for details).

With reference to the Arctic, Rosentrater & Ogden's (2003) cautionary note raises some important points. They said "presently, the magnitude of the threat of invasive species on Arctic environments is unclear: however, the potential impacts of this threat warrant [both] further investigation and precautionary action on species introductions, especially since climate change is expected to result in the migration of new species into the region". The need for precaution when there is a rapidly changing climate can apply to the whole of Europe, even although the temperature is likely to increase faster in the Arctic than in more southern parts of the continent. The risk to the environment and to biodiversity of intentionally introducing any non-native species must be established before the species is introduced. Experience worldwide indicates that it is often too late if the risk is assessed after the introduction; it might then also be too late to control the invasive species' spread and effects. Precautionary action is to stop the arrival of the invasive species in the first place because eradication later may be impossible, and even if it is possible then worldwide experience shows that it is likely to be extremely expensive.

3.10. Synopsis of anticipated changes

The brief review in section 3 has focussed on some of the topics that will most obviously affect biodiversity in a changing climate. These have included the overall number of species and communities and their geographical location, perhaps the aspects of most immediate significance when considering national biodiversity strategies, action plans and programmes. In other words, these reviews have addressed the topic of how a nation's biodiversity stock is likely to change in the most obvious manner. Other reviews have been addressed to more specific topics, such as changes in genetic diversity, changes in phenology, changes in migratory behaviour and the impacts of invasive species. In all of these topics, the changes could affect the biodiversity in European seas, fresh waters and on the land.

There are numerous other ways in which climate change might affect biodiversity. For example, in the drier parts of southern Europe, there may be changes in the wildfire regime. As McKenzie *et al.* (2004) in USA state, "if climate change increases the amplitude and duration of extreme fire weather, we can expect significant changes in the distribution and abundance of dominant plant species in some ecosystems, which would thus affect habitats of some sensitive plant and animal species. … The effects of climate change will partially depend on the extent to which resource management modifies vegetation structure and fuels". This clearly highlights the importance of the way that Europe's biodiversity is managed, as outlined in section 4.

Another area of considerable uncertainty is the deep sea, in the Mediterranean, the Atlantic Ocean, the Arctic Ocean, and the seas connected to these. In the deep waters of the eastern Mediterranean, Danovaro *et al.* (2004) showed that the 0.4^{o}C decrease in water temperature between 1992 and 1994 resulted in a significant decrease in nematode abundance but a significant increase in diversity. However, a recovery of the temperature after 1994/5 led to only a partial recovery of the previous abundance and biodiversity. Perhaps more interestingly, the cooling led to a greater similarity in the nematode biodiversity between the fauna of the eastern Mediterranean and that of the colder deep Atlantic. This finding demonstrates how even small temperature changes can have considerable, and perhaps unexpected, impacts on biodiversity.

All of these anticipated changes, possible changes, and indications of unexpected changes, imply that action needs to be taken to reduce the effects of climate change. This is not the place to argue for the Kyoto Protocol, or more importantly what might come as a successor to it, but rather to consider some of the responses that European nations might embrace. For example the 4th Ministerial Conference on the Protection of Forests in Europe, meeting in Vienna from 28 to 30 April 2003, issued the "Vienna Resolution 5" entitled *Climate Change and Sustainable Forest Management in Europe*. Amongst its clauses are the following

- "6. …by maintaining the carbon stock and enhancing carbon sequestration for forests in Europe through … national forest programmes or plans that provide appropriate guidance so that afforestation or reforestation takes due regard of environmental, in particular biodiversity, economic and social values, with a view to mitigating potential negative affects of large scale afforestation, …

- 7. support research and, as appropriate, monitoring activities to better understand the possible impact of climate change on forests and their goods and service, …

- 8. enhance policies and measures and develop forestry for a better adaptability of forests to climate change".

In many ways this collection of three bullet points underlines the key features of what European biodiversity conservation should also be aiming at. It should maintain or enhance the carbon stock within the biosphere, it should undertake research towards a greater understanding of the effects of climate change on biodiversity and the importance of biodiversity in maintaining ecosystem goods and services, and as outlined in the next section it should develop policies and measures so that biodiversity is better able to adapt to climate change.

4. Management responses within and outside protected areas

4.1. Overview

Given the variety and magnitude of anticipated changes in Europe's biodiversity as the climate changes during the next century, it becomes increasingly important that we should consider what responses we wish to make. The Berne Convention, the European Union's Birds and Habitats Directives, as well as many national Biodiversity Action Plans and Biodiversity Strategies, define the many species and habitats that, at the start of the 21st century, are considered to be priorities for conservation. Such lists are clearly biased towards some of the more obvious, more economically useful and more charismatic species, and were devised using criteria such as those used by the World Conservation Union (IUCN, 1994). They do not, however, focus on the key species for determining ecosystem function and hence in delivering those ecosystem services on which life on Earth depends.

This structure of this section follows a series of questions. What biodiversity do we have now? We need to know this in order to prioritise our actions. What is changing? Observations and models will assist us to know both the direction and speed of change. How do we manage biodiversity to resist, to ameliorate or to work with change? And finally, how do we record that change and inform both the public and policy makers?

4.2. Documenting existing biodiversity

European nations generally have complete inventories of their mammals, birds, reptiles and amphibians, although it is possible that a few more species might still be added (especially with taxonomic advances). European nations would also be able to provide good or reasonably good inventories for marine mammals, fish of both freshwater and marine environments, vascular plants and some groups of invertebrates (notably butterflies, dragonflies, some beetles and spiders).

Such lists, however, omit some of the most species-rich taxa. Large numbers of species of bryophytes (mosses and liverworts), lichens, fungi and algae occur, as do many other groups of invertebrate animals. Terrestrially it is likely that the insects and arachnids will prove to be the most species-rich, whereas in the sea it is likely to be the crustaceans and molluscs that are most species-rich. However, it should not be forgotten that there are many other taxonomic groups, especially the nematodes and many marine taxa of worms, sponges and hydroids, as well as innumerable single celled organisms in which the "species" concept is more difficult to apply. A particular area of comparative taxonomic ignorance relates to these micro-organisms, and possibly the meso-organisms, that inhabit soils and sediments. Whilst it is estimated that fewer than 5% of the bacteria in soil can be cultured by the techniques presently available, and hence identified, the effects of a changing climate on such important components of both terrestrial and aquatic ecosystems cannot be predicted. Advances in molecular biology will undoubtedly allow for such microbial communities to be better understood, but they cannot circumvent the problems of undertaking experimental research on these organisms.

Inventories have important roles to play: they form the basic building blocks for biodiversity conservation because, if you do not know what biodiversity you have, how can you start to conserve it or recognise when it is changing? After drawing up biodiversity inventories, items (species or habitats) can be assessed for their ability to survive into the future. For example, the IUCN (The World Conservation Union) has drawn up criteria for assessing the degree of threat to the continued existence of species (IUCN, 1994). Many nations have used these IUCN criteria as the basis for compiling their national "Red Lists". Species are allocated to the various threat groups on the basis of criteria, including the known or suspected reduction in a species' population size, the known or estimated decline in the range of the species, the total population size, and of the risk of extinction in the wild over a period of either a number of years or a number of generations. Analogous criteria could be derived for habitats. However, these criteria do not explicitly take into consideration the effects of climate change on either species or habitats.

Genetic diversity is also a part of the Convention on Biological Diversity. Many species have widespread distributions in Europe and occur in different habitats, landforms and communities. Measures of species richness underestimate genetic diversity and hence there is a need to increase documentation of genetic variation within species, especially in those that are of conservation concern. It is this genetic variability which is likely to be an important attribute in species' responses to climate change. Two examples illustrate genetic variability and emphasise the importance of understanding and maintaining genetic variation within species by conserving diverse populations - an application of the precautionary principle.

First, in Sweden, the rare, wood-inhabiting, polyporous fungus, *Famitopsis rosea*, illustrates the limitation of genetic variability resulting from the isolation of populations. Populations in isolated forest stands had a much narrower genetic structure than populations within the continuous taiga forests of Russia (Seppola, 2001). This suggests that habitat fragmentation can restrict genetic differentiation and potentially limit species' responses to environmental change.

Second, the genetic composition of populations of purple saxifrage (*Saxifraga oppositifolia*) and moss campion (*Silene acaulis*) determines their capacity to respond to short- or long-term environmental change. Current populations are derived both from survivors in refugia during the last glaciation and from migrants that colonised more recently. It is likely that heterogeneity of sites and populations, combined with the history of climate variation, has provided the present flora with the resilience to accommodate substantial and even rapid changes in climate without loss of species (Crawford & Abbott 1994; Crawford 1995).

The measurement of biodiversity, with its multitude of components (from the gene to the landscape) and its multitude of scales (from the local to planet Earth) is never going to be easy (Anon., 2003). It will require many trained scientists skilled in genetic analyses, taxonomy, ecology, and indeed a multitude of other skills. Such considerations lead to four recommendations. They are made without attempting to allocate responsibility for undertaking the work involved.

1. Train taxonomists who can draw up inventories of Europe's less well-known species, such as non-vascular plants, invertebrate animals, fungi and micro-organisms (protozoa, bacteria, etc.). Such species may be key players in the provision of ecosystem services.

2. Produce inventories of Europe's biodiversity (both species and habitats), indicating for each entry in the inventory where it occurs, the size of species populations or the extent of habitats. Such inventories need to be on a pan-European basis rather than on a national basis and need to be relevant to conservation (Bouchet *et al.*, 1999).

3. Assess the species and habitats of national or international priority on these inventories for their responses to climate change. An early example of such an exercise, based on professional judgement (Hill *et al.*, 1999), is the analysis of Scotland's legal responsibilities under the EU's Birds and Habitats Directives (and other priorities with the UK's Biodiversity Action Plan). More detailed approaches, based on modelling, are exemplified by the British and Irish MONARCH project (Harrison *et al.*, 2001). It is studies such as these that demonstrate which species

and habitats are at greatest risk due to climate change, and hence in greatest need of conservation action.

4. Improve knowledge of the genetic diversity of many species, which is at present poorly known (or even unknown). A considerable amount of research will be needed to explore this aspect of biodiversity, and conservation management will need to ensure that genetic diversity is either not lost or minimally lost.

4.3. Identifying changes in Europe's biodiversity

Change is already with us, and further change can be expected. It was shown in section 3 that each species is likely to respond in an individualistic way so that novel assemblages of species are very likely to occur in the future. Change in ecological communities is often referred to as "ecological succession". A preservationist attitude might be to maintain what we have today and hence manage a habitat in such a way as to oppose ecological succession. On the other hand, a conservationist attitude would be to work with ecological succession. This dichotomy of thinking is highlighted by Rhind (2003), who said "we have become fixated with the idea of preventing natural succession and, in most cases, would not dream of allowing a grassland or heathland to develop into woodland". Climate change will drive ecological succession and conservation management might have to work with these changes rather than necessarily trying to oppose them.

Species might themselves adapt to new environmental conditions if they have both sufficient genetic diversity and sufficient time. The genetic level of biodiversity allows populations to meet the challenges of an extremely variable and changing environment, and this genetic variation ensures persistence of the populations, at least in the short to medium term. Over the longer term, such genetic diversity is the basis for evolutionary change leading to the emergence of new subspecies and species. With predictions of a rapidly changing climate, genetic diversity is important in the sense that it assists species to be able to meet the environmental challenges that they will face. But will the speed of climate change be too fast for the species to be able to adapt?

Predictions are usually based on professional knowledge or on models. The concept of modelling biodiversity conservation is in the domain of statistical models rather than precise models that give a definitive result (Starfield & Bleloch, 1986). However, despite such limitations, models are useful in endeavouring to explore the likely changes in biodiversity. For example, in Finland models have been used to predict the likely changes in the distribution of the major forest tree species – pine (*Pinus sylvestris*), spruce (*Picea abies*) and birch (*Betula* spp.) – predicting the movement north of the two coniferous trees (Kuusisto *et al.*, 1996). At the same time, the models have predicted that, whereas at the present time only the southern fifth of Finland is thermally suitable for the cultivation of spring wheat, by 2050 it is likely that this proportion will increase to the southern half of Finland.

These considerations of change lead to two further recommendations.

5. Work with ecological succession, and not against it, in the management of Europe's biodiversity. Incorporate this thinking into all aspects of the management of biodiversity in the sea, in fresh water and on the land, but especially in protected areas.

6. Develop further the models that can be used to explore changes in biodiversity under the various scenarios of climate change. Undertake the research needed to provide data to parameterise the models for key species and habitats.

4.4. Managing Europe's protected areas

The establishment of protected areas has been a core aspect of conservation legislation and activity throughout the world. The concept is implemented in different ways by different national governments, with differing degrees of success, as becomes clear in reviews of international activities (e.g. IUCN, 1991). The aim of this section is not to review the variety of systems, but instead to review the underlying ecological concepts related to the conservation of biodiversity and the effects that climate change might cause.

In general, the establishment of protected areas is seen to have a scientific foundation. As Kingsland (2002) said "… its goal is to apply scientific ideas and methods to the selection and design of nature reserves and to related problems, such as deciding what kinds of buffer zones should surround reserves or how to establish corridors to link reserves and allow organisms to move from one area to another. As in other areas of conservation biology, designing nature reserves is a "crisis" science, whose practitioners are driven by an acute sense of urgency over the need to stem the loss of species caused by human population growth". This to some extent misses a vital point: the social sciences are also involved with conservation. Why do we think it important to conserve biodiversity, why do we favour particular species over others, and how do people fit into the conservation framework? Such sociological questions will not be discussed here; this section will focus on the scientific bases of conservation.

Three main facets of ecological thinking have affected the design of potential protected areas. The concepts of island biogeography (MacArthur & Wilson, 1967), of fragmentation of habitats and the establishment of metapopulations (Harris, 1984), and of corridors (Saunders & Hobbs, 1991), are not unrelated, but they can all affect our views of protected areas in a changing climate. Island biogeography has been used to justify larger protected areas rather than smaller ones. With climate change, and with many European wildlife populations and their geographical ranges likely to diminish, the use of the precautionary principle would also suggest that larger rather than smaller protected areas should be established. Fragmentation of ecosystems has tended to be viewed as the "islandisation" of habitats. Although fragments cannot be thought of as real islands, the use of island biogeographical concepts in the formulation of "rules" for the design of protected areas has been fashionable, with size and shape being the key factors (Diamond, 1975; Usher, 2002b). With fragmentation being an integral part of modern development, corridors have appeared to be a useful concept. Albeit beguilingly simple, at the present time neither the value of corridors, nor their lack of value, has been proven.

With climate change happening, it is therefore best to avoid the necessity for corridors by focussing on larger protected areas and a reduction of the processes that lead to habitat fragmentation. This will promote real connectivity, rather than apparent connectivity, for both species and habitats. However, will the protected areas that exist today, even if they have been located in the best possible place to conserve biodiversity, still be effective in the future with climate change? The answer might be "no". Designations have been widely used, but they are based on assumptions of climatic and biogeographical stability; sites are usually designated to ensure the maintenance of the *status quo*. All the available evidence indicates that these assumptions will not necessarily be sustainable during the next century. So what can be done to make the network of protected areas more appropriate in the future climate of Europe? Carefully planned and executed actions now will be vital for securing the conservation of biodiversity into the next century and beyond.

First, today's protected areas should also encompass land or water that will potentially be useful for biodiversity conservation in the future. Models of the changing distribution of species and habitats will be useful, and their outputs should be included in the design of protected areas. This means that designation should be on the basis of both the present value of the areas for biodiversity as well as on the predicted future value (the potential value).

Second, boundaries may need to be more flexible. In general boundaries are lines on maps, enshrined in legislation, and hence difficult to change. Perhaps the present practices could be described as having "hard boundaries". What might be needed is that the boundaries could be changed in the face of a changing distribution of the flora or fauna being protected. In other words, over time (probably viewed as decades rather than years) the location of the protected areas would shift geographically (this could be described as the protected areas having "soft boundaries"). This will need care so that sociological and developmental pressures do not destroy the value of the protected areas in safeguarding the biodiversity that is their *raison d'etre*. However, little would be worse than in 50 years time having a network of sites that were protecting very little! More flexible systems of designation, adding areas which are or will become important, and dropping areas that are no longer important, would potentially be one of the possible ways forward; it appears that such a system of designations with "soft boundaries" has never been tried in the world.

Protected areas derive from the major policy imperative to conserve biodiversity (as well as to conserve historical and cultural artefacts). Climate change might cause priority habitats and species to move out of designated areas, whilst at the same time habitats and species new to the area will tend to colonise or visit, especially from the south or downslope. Assemblages of species without current analogues might form as individual species respond to climate change at different rates and in different ways. It will therefore be necessary to adjust such concepts as "representative communities" and "acceptable limits of change" that are part of the mandate of Natura 2000 designations of habitats. The expected changes might include many surprises resulting from the complex interactions that characterise ecosystems and the non-linearity (or threshold effects) of many species' responses.

The scientific basis of biodiversity conservation planning in the era of climate change argues against procedures designed to maintain a steady state. There are four general policy options to respond to climate change that have been used in the Canadian national parks (summarised by Scott & Lemieux, 2003), as outlined in Table 1. It is likely that either adaptive management (or hybrid management involving some aspect of adaptive management) will be the most widely applied. These are likely to include actions to maintain, for as long as possible, the key features for which the original designation was made, for example by the adjustment of boundaries and by the development of management practices to adapt to climate change. Past experience has shown that intervention strategies will tend to be species-specific, but this must not detract from the more scientific and sustainable goal of conserving Europe's biodiversity in a holistic manner.

Type of management	Description of management type
Static	Continuation of management and protection of current habitats and species within current protected area boundaries, using current goals
Passive	Acceptance of ecological responses to climate change and allowing evolutionary processes to take place unhindered
Adaptive	Maximisation of the capacity of habitats and species to adapt to climate change through active management (for example, by fire suppression, species translocation or suppression of invasive species), either to slow the pace of ecological change or to facilitate ecological change towards a new climate-adapted state
Hybrid	Some combination of two or more of the management types above

Table 1. Four possible types of management of protected areas in the face of climate change. These approaches have been developed for the Canadian national parks (Scott & Lemieux, 2003).

Europe has valuable international networks of protected areas (the Natura 2000 and Emerald Networks) together with other national series of protected areas. The need now is to analyse how climate change is likely to affect each of the protected areas. Such work has been carried out for the Canadian national parks (Scott & Suffling, 2000), stressing the importance of sea level rise for the many national parks that are located on the coast. Although the coast is important, in Europe it is also the mountain and upland areas, as well as the Arctic north, that perhaps need most consideration. These thoughts give rise to a further recommendation.

7. Assess each protected area for the likely effects of climate change, and in the light of this assessment review the methods of management and any necessary revisions of the area's boundary. In undertaking these reviews, one of the important questions to answer is whether or not the protected area is conserving (or will conserve) what we think that it was designed to conserve. This is not always a simple task, especially with year-to-year variation in population sizes and with longer term changes in habitat quality, but such assessments are now becoming more commonplace (e.g. Parrish *et al.*, 2003). Management prescriptions and practices to address the impacts of climate change will have to be developed for each protected area.

4.5. Managing Europe's biodiversity in the wider environment

Protected areas are just one method of endeavouring to conserve Europe's biodiversity. Although biodiversity conservation is the primary focus of management within protected areas, they will only ever cover a relatively small proportion of Europe's land and water area, and thus they will only contain a small proportion of Europe's biodiversity resource. Hence, it becomes imperative that biodiversity is also considered in the land and water outside protected areas. Forms of integrated management need to be adopted whereby biodiversity is not forgotten amongst all of the other competing claims for space on land or at sea.

One of the first requirements is to collate information about the best way to manage biodiversity in a changing climate. This will be based on knowledge gained by scientists, either through observation or experiment, though in some parts of Europe traditional knowledge is also helpful and should be considered by any planners. There has been a number of attempts to bring together guidelines for best practice, usually either in a nation or for a particular sectoral area. An example would be the guidelines developed in Finland for practical forest management (Korhonen *et al.*, 1998). They integrate concern for the environment with the needs of production forestry, and the use of forests for recreation, protection of the quality of both soil and water, and the management of game species. They provide an example of what can be done when all of the interest groups work together towards the common goal of the sustainable use of biodiversity resources. This underlines the need of preparing best practice guidelines for managing all aspects of Europe's biodiversity.

The need is to incorporate biodiversity thinking into all forms of policy development, not just environmental policies, but also policies about education, health, development, energy, tourism and transport. This wider environmental approach for biodiversity conservation ensures that more of Europe's biodiversity is likely to be protected in the face of a changing climate than by relying solely on the protected areas. These considerations give rise to two further recommendations.

8. Explore and implement integrated forms of management, incorporating the requirement for biodiversity conservation, for all uses of the land, fresh waters and the sea.

9. Incorporate biodiversity conservation into all policy development, be it regional, national or international, with the aim of all biodiversity resources being used in a sustainable manner.

In order to assist in these processes, the "ecosystem approach", sometimes also referred to as the "ecosystem-based approach", has been advocated (Hadley, 2000). This sets out a series of 12 principles, some of which are science-orientated, but all of which form an essentially socio-economic context for conservation. Principle 5 focuses on ecosystem services and states "conservation of ecosystem structure and function, in order to maintain ecosystem services, should be a priority target for the ecosystem approach". Principle 10 states "the ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity". Since the ecosystem approach is still comparatively new, its details have as yet been worked out in very few situations. Hence, a further recommendation is that

10. Trial the Ecosystem Approach (or Ecosystem-based Approach) for a number of situations in Europe, so as to assess its ability to harmonise the management of land and water for the benefit both of people and of wildlife.

These concepts were implicitly enshrined in the *Convention on Biological Diversity*, the final text of which was agreed at a conference in Nairobi, Kenya, in May 1992. Within a year, the Convention had received 168 signatures. As a result of this, the Convention came into force on 29 December 1993, and there is now very considerable international activity to implement the Convention in the majority of nations on the Earth, including all European nations.

4.6. Monitoring and indicators

Monitoring (or surveillance) involves the periodic recording of data so that trends can be detected. Usually it also involves assessing the progress towards some target, but often it only involves determining if the resource still exists and how the amount of that resource is changing. Indicators are regularly monitored measures of the current state of the environment, the pressures on the environment, or the human responses to changes in that state. These three points are often referred to as the "pressure-state-response model" (Wilson *et al.*, 2003). It often happens that it is easier to find indicators of state rather than indicators of either pressure or response.

Monitoring of wildlife has a long history. There have been interesting attempts to coordinate monitoring, as for example in the Nordic Nations (From & Söderman, 1997). Their aim was "to monitor the biodiversity and its change over time with appropriate and applicable mechanisms, and to monitor the cause-effect relationship between pressure and response on biodiversity by using specific biological indicators".

Five implications follow from these objectives. First, the programme excluded chemical and physical aspects of environmental monitoring. Second, one focus was on ecosystems and species; the data would be analysed in the simplest manner to provide appropriate qualitative and quantitative information. Third, another focus was on anthropogenically induced changes, though the analyses would need to distinguish these from natural changes. Fourth, monitoring would include *inter alia* threatened habitats and species, and hence their disappearance or extinction would become known. Finally, the monitoring would not directly focus on administrative performance indicators, though it might provide important information in understanding these. The main problem with this Nordic monitoring programme is that it relates only to the terrestrial environment, though this does include wetland and coastal habitats. More attention would need to be paid to the marine environment.

Monitoring is widely advocated. For example, BirdLife (2000) indicated that it wished to "monitor and report on progress in conserving the world's birds, sites and habitats", but also that it wished to monitor the effectiveness of its work in achieving the objectives set out in its strategy. It is vitally important to assess what to monitor when there are so many species, etc., that could be monitored. Burke (2004), for example, suggested that the species in what she termed "special habitats" could provide the most suitable indicators of climate change.

Surveillance is also a necessary part of the conservation of biodiversity. As discussed in section 3.9, climate change could have far-reaching implications for the arrival on non-native species in Europe, and for their consequent adverse effects on Europe's biodiversity. Early warning systems are therefore important because it is much easier, and less resource intensive, to control or eradicate non-native species when their numbers are small or when the geographical area of occupancy is very limited. Similarly, surveillance can detect changes in the behaviour of migratory species (section 3.8). Although it might be difficult, or impossible, to undertake any management action that could re-instate the original behaviour, it is possible that assistance could be given to migratory species that are in some way threatened by climate change.

Usher (1991) posed five questions about monitoring. These related to the purpose (what are the objectives?), the methods to be used (how can the objectives be achieved?), the form of analysis (how are the data to be analysed statistically and stored for future use?), the interpretation (what might the data mean and can they be interpreted and communicated in an unbiased manner?), and fulfilment (when will the objectives have been achieved?). All five of these questions should be asked and answered before a monitoring scheme begins because *ad hoc* monitoring programmes might provide data that cannot be analysed statistically, and hence the confidence that can be placed in resulting trends, etc., is minimal.

International efforts at monitoring are ongoing. For example, the Global Terrestrial Observing System (GTOS), led by the UN's Food and Agriculture Organisation, has a hierarchy of spatial scales, and it incorporates a considerable number of Terrestrial Ecosystem Monitoring Sites (TEMSs). GTOS has developed a Biodiversity Module with seven core variables to guide development in the programme (threatened species, species richness, pollinator species, indicator species, habitat fragmentation, habitat conversion, and colonisation by invasive species). The relationship with the sister programmes, Global Ocean Observing System (GOOS) and Global Climate Observing System (GCOS), needs to be clarified, but together they form an important monitoring network

In order to reduce the amount of work required, indicators are often advocated. For indicators to be valuable, they should ideally fulfil at least four criteria (modified from Wilson *et al.*, 2003). First, they should reflect the state of the wider ecosystems of which they are a part. Second, they should have the potential to be responsive to the implementation of biodiversity conservation policies. Third, they should be capable of being measured reliably on a regular (not necessarily annual) basis, and should be comparable with similar measures at larger geographical scales. Fourth, they should have, or have the potential for, strong public resonance. An additional criterion might also be that the indicators contribute to our understanding of sustainability (Carruthers & Tinning, 2003).

These discussions lead to three further recommendations.

11. Fully implement monitoring networks throughout the Europe. Collect and analyse data on the state of Europe's biodiversity, on the drivers of change, and on the effectiveness of responses to those changes and use these results in the development of future European and national biodiversity policies.

12. Implement surveillance networks to identify the arrival (or occurrence) of non-native species and changes in the behaviour of migratory fauna. On the basis of such surveillance, initiate schemes to control or eradicate non-native species and, where possible, to assist migratory species.

13. Devise and agree a suite of indicators to assess the impact of climate change on biodiversity, undertake the monitoring for them, and make the results available in a format (or formats) so as to inform public opinion, educators, decision-makers and policy-makers.

5. Conclusions and recommendations

Biodiversity is not the easiest of concepts to grasp. On the biological side, biodiversity has to be considered at three scales – the variation within species (genetic diversity), the variation between species (species diversity) and the variation amongst assemblages of species (habitat diversity). Whereas habitat diversity in Europe's land, fresh water and sea would probably be measured in thousands of habitats, species diversity would be measured in tens or hundreds of thousands of species, and genetic diversity would be measured in millions or billions of genes. These can all be influenced by a changing climate. On the geographical side, biodiversity can be considered at many different scales, from that of the individual plant or animal and its immediate surrounds to the whole planet. Again a changing climate can affect each of these scales, and indeed the effects at one scale may be different to the effects at another scale.

Herein is the difficulty in conserving Europe's biodiversity. Amongst this multitude of scales, what are the priorities? Should the primary focus be on habitats, species or genes? Which of the many spatial scales is the more important? It is clear that not every aspect of Europe's biodiversity can be conserved, so priorities have to be attached to management actions that can conserve the greatest amount of biodiversity or, in some situations, the greatest amount of useful biodiversity. But to set these priorities, information is required about the present state of biodiversity, about how it is changing and, by using models, about how it is likely to change. It is in this context that the recommendations in section 4 have been made, and action on them should assist in conserving Europe's biodiversity into the future. It is also in this context that a further recommendation can be made.

14. A large scale, pan-European, scientific study needs to be undertaken, exploring the impacts of climate change on the biodiversity of Europe and on the uses of Europe’s land, fresh water and seas. The study also needs to focus on the inter-relationships of all of these factors with human society, economy and health.

A study of the effects of climate change on the people, wildlife and environment of the Arctic has recently been completed – the Arctic Climate Impact Assessment (www.acia.uaf.edu), with contributions from the six European nations (Denmark [Greenland], Finland, Iceland, Norway, Russia and Sweden) that have Arctic territory. A similar assessment for Europe has not been undertaken, and could usefully incorporate the knowledge of scientists and social scientists from the many European countries. Climate change will undoubtedly affect the way that Europe’s people use their land and water resources, and hence it is important to understand how such use will affect biodiversity, and equally how biodiversity can influence people’s choices about how to use both land and water.

This collection of 14 recommendations, as related either explicitly or implicitly to the Berne Convention, are listed in Table 2.

Number	Section	Brief summary of recommendation
1	4.2	Train taxonomists who can draw up inventories of Europe's less well-known species, such as non-vascular plants, invertebrate animals, fungi and micro-organisms (protozoa, bacteria, etc.).
2	4.2	Produce inventories of Europe's biodiversity (both species and habitats), indicating for each entry in the inventory where it occurs, the size of species populations or the extent of habitats.
3	4.2	Assess the species and habitats of national or international priority on these inventories for their responses to climate change.
4	4.2	Improve knowledge of the genetical diversity of many species, which is at present poorly known (or even unknown). A considerable amount of research will be needed to explore this aspect of biodiversity, and conservation management will need to ensure that genetic diversity is either not lost or minimally lost.
5	4.3	Work with ecological succession, and not against it, in the management of Europe's biodiversity. Incorporate this thinking into all aspects of the management of biodiversity in the sea, in fresh water and on the land, but especially in protected areas.
6	4.3	Develop further the models that can be used to explore changes in biodiversity under the various scenarios of climate change. Undertake the research needed

		to provide data to parameterise the models for key species and habitats.
7	4.4	Assess each protected area for the likely effects of climate change, and in the light of this assessment review the methods of management and any necessary revisions of the area's boundary. In undertaking these reviews, one of the important questions to answer is whether or not the protected area is conserving (or will conserve) what we think that it was designed to conserve. Management prescriptions and practices to address the impacts of climate change will have to be developed for each protected area.
8	4.5	Explore and implement integrated forms of management, incorporating the requirement for biodiversity conservation, for all uses of the land, fresh waters and the sea.
9	4.5	Incorporate biodiversity conservation into all policy development, be it regional, national or international, with the aim of all biodiversity resources being used in a sustainable manner.
10	4.5	Trial the Ecosystem Approach (or Ecosystem-based Approach) for a number of situations in Europe, so as to assess its ability to harmonise the management of land and water for the benefit both of people and of wildlife.
11	4.6	Fully implement monitoring networks throughout the Europe. Collect and analyse data on the state of Europe's biodiversity, on the drivers of change, and on the effectiveness of responses to those changes and use these results in the development of future European and national biodiversity policies.
12	4.6	Implement surveillance networks to identify the arrival (or occurrence) of non-native species and changes in the behaviour of migratory fauna. On the basis of such surveillance, initiate schemes to control or eradicate non-native species and, where possible, to assist migratory species.
13	4.6	Devise and agree a suite of indicators to assess the impact of climate change on biodiversity, undertake the monitoring for them, and make the results available in a format (or formats) so as to inform public opinion, educators, decision-makers and policy-makers.
14	5	A large scale, pan-European, scientific study needs to be undertaken, exploring the impacts of climate change on the biodiversity of Europe and on the uses of Europe's land, fresh water and seas. The study also needs to focus on the inter-relationships of all of these factors with human society, economy and health.

Table 2. A summary of the 14 recommendations made in section 4 of this paper. The section in which the recommendation is made is given in the second column, where fuller information about the recommendation can be found.

Many of recommendations in Table 2 would support the conclusions of a study by the World Conservation Monitoring Centre and other organisations (Anon., 1999). It concluded that "climate change is already happening and it is affecting wildlife and wildlife habitats now. Current policies and approaches to nature conservation must be widened to cope with climate change". It is clear that Europe needs to develop strategies for coping with the effects of climate change on the continent's biodiversity, and that such strategies will require rather different approaches from those used in the past.

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