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Climatic change and the conservation of migratory birds in Europe: identifing effects and conservation priorities

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EXECUTIVE SUMMARY

Introduction

Birds are one of the best groups of animals for monitoring the effects of climate change. They are day-time active, conspicuous, easy to identify, and are popular with many groups of people, including amateur birdwatchers and professional scientists. In many parts of Europe, their distributions and numbers, as well as the timing of their migrations and breeding seasons, have been well monitored for decades.

Migratory birds are likely to be more vulnerable than non-migrants because they can influenced by conditions in three different geographic locations: their breeding grounds, their wintering areas, and their migration routes. Individual birds also experience "carry-over effects," such as when conditions experienced in wintering areas influence subsequent breeding success, or when conditions experienced on the breeding grounds influence subsequent over-winter survival.

Furthermore, field evidence indicates that large numbers of migrants can be are killed by storms encountered when they are migrating. Climatologists predict that storms and other extreme events are likely to increase in frequency in the years ahead. Therefore we can expect that migrants will suffer greater storm-induced losses, which could cause noticeable reductions in populations regardless of other climate changes.

Responses of migratory birds to climatic changes

A growing body of field and laboratory evidence indicates that far from being a static and conservative trait; migration is a dynamic and flexible behaviour in birds that is greatly influenced by external factors. Thus we can expect that in addition to population effects in migrants, migratory behaviour, itself, is likely to change in association with climate change. And, indeed, many changes in migration already have been reported. Many migrants are migrating earlier in spring than formerly, and some are migrating later in autumn as well. As a result, individuals of some species stay for longer on their European breeding areas. Most examples of shifts of increased migratory behaviour involve species that have extended their breeding ranges into higher latitude areas where over-wintering was not possible or was costly in the past. On the other hand, some species that once were entirely migratory are now partially migratory, with increasing numbers of individuals staying on their breeding grounds year-round. In yet other species, individuals are now migrating shorter distances than formerly, and are over-wintering farther north. One example of the latter is the increased proportion of White Storks that now over-winters in southern Spain, rather than migrating to Africa. In some species these changes may be beneficial or neutral to populations. In others they may be harmful. Almost all of these changes are associated with changes in food-availability, or with climatic conditions that are likely to affect food-supplies, such as milder winters.

Some of the observed changes in migratory behaviour appear to represent immediate behavioural or "facultative" responses to prevailing conditions, whereas others may reflect genetic changes brought about by natural selection. Despite difficulties of detecting the latter, there is evidence from a few species that indicates a genetic basis for changes in migration timing, and, at least for one species, a genetic basis for changes in migration intensity and the direction of migratory travel. Most changes in migratory behaviour are likely to start as facultative responses and then become genetically based as natural selection acts over time.

One situation that has come to light in studies of biological responses to climate change is that different plants and animals often do not respond at the same speed and magnitude to climate change. As a result migratory birds that once arrived on their breeding areas when their food-supplies were reaching their peaks now arrive either too early or too late to take immediate advantage of this situation. Furthermore, those arriving too late are likely to breed less successfully, resulting in population declines.

The breeding ranges of some European birds are already shifting north, as individuals withdraw from southern portions of their ranges, while others spread north at the northern limits of their ranges. A particular concern involving range shifts is the loss of mountain-top breeders, which may disappear from much of their range, as global warming reduces the extent of specific high-mountain habitats.

Some measures taken to combat the causes of climate change, such as the development of wind farms, could themselves severely impact migratory birds. This is particularly so if wind farms are sited improperly along major migration routes, where large numbers of migrants could then be killed by colliding with rotor blades.

Suggested actions

1. We recommend establishing a functional network of watchsites or “watchtowers” for monitoring changes in bird behaviour and assessing bird-population trends in Europe. Considerating the relative geographic importance of certain sites at a continental scale, as well as an ongoing tradition for migration monitoring, these watchtowers should include at minimum:

- Falsterbö, in southwestern Sweden
- Fair Isle, in northern Scotland
- Texel, in northwestern Holland
- The Strait of Gibraltar, near Tarifa, Spain
- Southern Italy, including the Strait of Messina
- Elat, in southern Israel

2. In addition to this network of monitoring sites, we recommend establishing a set of focal species whose populations and behaviour should be monitored because of their relationships with more-difficult-to-follow but critical biological variables, including overall biological diversity and changes to habitats of special interest, etc. Specifically, we recommend the focused monitoring of seabirds, wetland birds, diurnal birds of prey or raptors, other soaring birds, and several widespread and long-term studied songbirds.

3. An increasing body of evidence suggests that as climate change alters existing landscapes current networks of natural areas will no longer hold many of the target species and habitats they were designed to include. Complementary policies are needed. “Land custody” or, land stewardship via easements, is a flexible habitat-protection strategy that could be used to maintain critical landscape features, track changes in biodiversity, engage the general public, and involve private landowners in natural resource conservation. Public interest in this land-use strategy could be increased with tax incentives and tax benefits for participating landowners. An additional strategy designed to reduce species losses, would be to incorporate linear infrastructures including power-line, road, and rail rights-of-ways, as a supplementary wildlife corridors for organisms moving in responses to climate change.

4. Historically, most migration studies have occurred in the middle and northern latitudes of Europe. Whereas these studies need to continue, there is a particular need to increase the numbers of studies further south in southern Europe, where many migratory birds over-winter, and where many others pass through while migrating between European breeding grounds and African wintering areas. One particularly good location for additional migration study is southern Spain, near the Strait of Gibraltar, through which an array of species migrate in both spring and autumn.

TABLE OF CONTENTS

1. INTRODUCTION

Climatic change is a major factor that is likely to affect the earth's ecosystems in the coming decades. The increase in global surface temperature in the last century was the largest in any century during the past 1,000 years. This change in temperature has been associated with changes in weather patterns, including precipitation and snow cover, as well as changes in sea temperatures and sea level. Climate change is a phenomenon that currently can be recognized by many indicators. The impacts of climatic change affect not only species and ecosystems but also human economy and society. We face a potentially serious problem, both for us and our environments.

There is compelling evidence that animals and plants have been affected by recent changes in climate. Migratory species, which travel long distances and are subject to a wide range of environmental influences and that rely on a wide range of natural resources, are particularly likely to be affected by climate change.

The primary instrument for migratory species conservation is the Convention on the Conservation of Migratory Species of Wild Animals (Bonn 1979, ratified by 101 parties by 2007). CMS recognises that states have a duty to protect migratory species that live within or pass through their boundaries and that their effective management requires concerted action from all states in which a species spends parts of its life-cycle. Under CMS framework, specific agreements can be made as Memoranda of Understanding among appropriate states.

The Convention on the Conservation of European Wildlife and Natural Habitats (Bern, 1979) aims to conserve wild flora and fauna and their natural habitats, especially those species and habitats whose conservation requires the co-operation of several States. With the addition of Serbia and Armenia, the Bern Convention will have 47 Contracting Parties in 2008. By joining the Convention, States have undertaken to co-ordinate their efforts for the protection of the migratory species listed in Appendices II and III whose range extends into their territories. The Bern Convention gives also special attention to the protection of areas of importance for those migratory species listed and, in particular, in relation to migration routes, such as wintering, staging, feeding, breeding or moulting areas.

The present report has been prepared for discussion by the "Group of Experts on Biodiversity and Climate Change" of the Council of Europe, set up under the Bern Convention. The report (1) asseses the current scientific evidence linking climate change and the behaviour, distribution, and abundance migratory species of birds, (2) identifies what effects climate change may have on migratory birds in the future, and (3) suggests an adaptive management strategy for the conservation of migratory species of birds and the phenomenon of bird migration itself, in the face of the climatic change.

2. CLIMATE CHANGE

Earth's climate is currently changing. Although climate change has occurred throughout earth's history, the current rate of change, the fact that we are present to be impacted by it and the growing body of evidence indicating that we are responsible for it, all suggest that we should attempt to reduce its impacts wherever possible. Over the course of the last century, global average surface temperature has increased by around 0.6ºC, and precipitation has increased, particularly over mid- and high-latitudes. These changes, in turn, have affected the extent of both global ice cover (decreasing) and sea-levels (increasing).

The ongoing increase in temperature resulted from increased concentrations of carbon dioxide and other greenhouse gases in the atmosphere, which reduces radiative heat loss from earth. As a result of burning fossil fuels and other human activities, carbon dioxide concentrations have risen by 32% from about 280 ppm in pre-industrial times to about 370 ppm at present. If this trend continues, carbon dioxide levels are expected to exceed 400 ppm by the year 2100, causing a mean global temperature rise of 1-4 ºC in the coming century. Increased surface warming is likely to increase the frequency and intensity of climatic extremes, including tropical cyclones, flooding, and droughts.

Sea-levels are forecast to rise at rates of 30-50 cm per century, flooding many fertile delta regions and low-lying islands. Over much of the world, glacial areas will be restricted to higher latitudes and altitudes, and animals and plants that depend upon them will be further restricted as well. Pollen records suggest that in most instances trees can shift their ranges by about 200-400 m annually (Davis 1981, King & Hertrom 1997). Under the current rate of climate change, July isotherms are expected to advance northward at 4-5-Km annually. If trees were to track this rate of change they would need to migrate 10-25 times faster than the mean rate exhibited by the pollen record. In this situation it is difficult to predict the impacts of climate change on plants and animals.

Another problem in predicting future biota distribution is that large parts of the landscape have now been converted to human use and, as such, are closed to most of the wild animals and plants. In fact, many areas provide no broad-front dispersal route, but, at best, a series of narrow interrupted corridors and stepping stones, thereby impeding or preventing the movements of many organisms. The ongoing situation is likely to favour plants with short response times, namely herbs, shrubs and fast-growing trees, whereas slow-growing trees with long generation times and poor dispersal characteristics could be particularly disadvantaged. Although animals are more mobile than plants, they also are restricted to areas of suitable vegetation.

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3. MIGRATORY BIRDS IN EUROPE

The environmental conditions for life on our planet are characterized by the continuous influence of a geophysical cycle with annual periodicity. “Seasonal Earth” results from the planet’s rotation around the sun together with the degree of inclination of its axis of rotation, resulting in the four climatic seasons in most part of the world. The seasons bring with them constant changes in environmental conditions to which animals must adapt if the are to survive and reproduce. A common response to seasonal periodicity is migration.

Diverse forms of seasonal migration have developed in response to the seasons. The simplest cases are vertical migrations in a geographically limited environment. In birds too, some of the simplest seasonal migrations are vertical. Many alpine birds migrate down to the valleys to spend the winter. In European high mountains and subalpine regions this behaviour is exhibited by Alpine Choughs (*Phyrrycorax graculus),* the Water Pipits (*Anthus spinoletta*), and Wallcreepers (*Tichodroma muraria*) among others (Berthold 2006).

Seasonal long-distance migrations can be found in many arthropods. Marine crustacea can migrate for several hundred kilometres on the bottom of the sea. The American Monarch butterfly (*Danaus plexippus*) migrates up to 4000 Km from Canada to Mexico, and the Red Admiral (*Vanessa atalanta*) is believed to migrate from northern Africa over the Mediterranean into Scandinavia. Seasonal long-distance migration is pronounced in all vertebrate classes, including fish, amphibians, reptiles and mammals. But no class exhibits the complexity and extent of the migration of birds (Berthold 2006).

Birds are especially adapted to migration due to their capacity for active flight, their size, and their homoeothermy. Birds are present in virtually all parts of the Earth, and their migratory routes cover most of the Earth’s surface. In extreme cases migrants cover distances equivalent to the circumference of the planet. The number of bird species that migrates varies with latitude. In the northern hemisphere, less than 10% of tropical species undertake migratory journeys, this proportion increases with distance from the equator, and more than 80% of all species above the Arctic Circle migrate. Climate induced changes in the habitat are predicted to be greatest in the Arctic, where the importance of migratory species is highest. In Europe, more than 60% of the roughly 400 breeding bird species are partial migrants (species in which some individuals migrate, but others do not), and it is highly likely that the remainder, are also genotypical partial migrants (i.e. potential partial migrants whose genome contains genes that can induce sedentary behaviour under certain conditions, Bertthold 1999).

Migratory birds are perhaps the best group of animals on which to monitor the effects of climate change. They are diurnal in habits, conspicuous and easy to identify, and are popular with many people, including scientists. In various parts of Europe, their distributions and numbers have been well monitored for decades, as has the timing of their migrations and breeding seasons. Migratory birds are perhaps more vulnerable than most species to climate change, because they can be influenced by conditions in their disjunct breeding grounds and wintering areas, as well at sites along their migration routes. Research has shown that populations of some migratory birds are limited by conditions in wintering areas, whereas those of others are limited by conditions in breeding areas, or at stopover sites along migration routes. Individual birds also experience carry-over effects, in that conditions experienced in wintering areas can influence subsequent breeding success; and conditions experienced on the breeding grounds can influence subsequent over-winter survival.

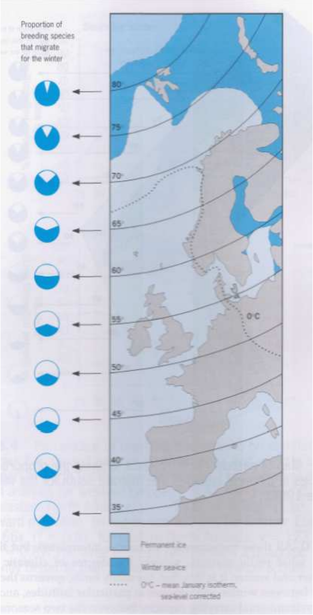


Figure from Newton (2003) showing the cline of percent of migratory birds according latitude in Europe.

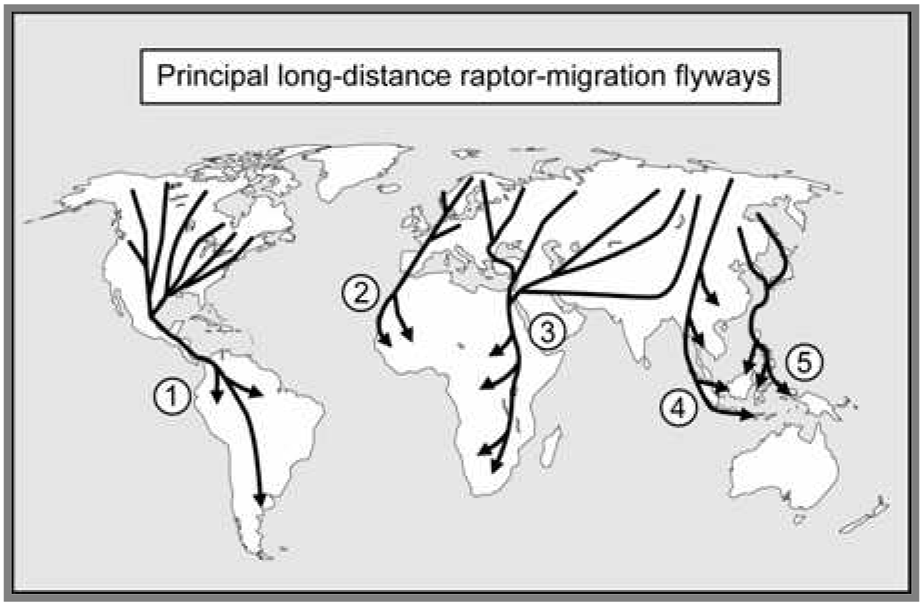
There is no doubt that bird migration originated in the tropics, or at least in tropical-subtropical conditions. This is supported by the observation that most long-distance migrants of the northern hemisphere have closely related, non-migratory or partially migratory forms in the tropics (Rappole 1995). Migration under tropical conditions initially covered only short distances and from the beginning included partial migration. However partial migration may have evolved (Bildstein 2006), it has proved to be an extremely successful and adaptable life force, and has become increasingly widespread.

Once partial migration was genetically anchored in a species, the movement ecology of populations within it could range from entirely sedentary to completely migratory depending upon ecological circumstances, and within the latter, intercontinental, long-distance migration could evolve as conditions merited. Selection experiments involving captive song birds suggest that the transformation from migratory to sedentary population (or vice versa) in the wild could occur within about 25 generations or 40 years (Berthold 1999).

Recent ice ages certainly played a major role in the development of bird migration in and out of Europe. At the height of ice coverage in the Northern Hemisphere the avifauna of Europe was greatly reduced (Moreau 1954), only to increase during intervening warm periods. The current bird migration system in Europe, which emerged at the end of the last ice age, 15 000 years ago, is still developing (Berthold 2006).

Migrant birds also are important vectors for different forms of life, including plants, fungi, algae, and many microorganisms. As a result, migratory birds can be a major factor in determining the distribution of other life forms. Populations of migrating birds can also serve as reservoirs for diseases and can spread disease-causing agents to humans, their livestock, and plant resources. In an overview of the subject, Gerlach (1979) lists viruses, *Rickettsia*, *Chlamydia*, bacteria, and fungi as disease vectors that can be spread by birds either through direct infection or through the ectoparasites carried by birds. Cases of toxoplasmosis and Haemosporidia (i.e. protozoans) have been reported (Aspöck &

Hermentin 1987, Valkjunas 1989). This widespread transport has been closely studied. An examination of over 5,000 birds in Austria has revealed that many arboviruses are regularly transported by migratory birds (Wojta & Aspöck 1982). Transported infections include Q fever, typhus fever, pseudo-tuberculosis, Newcastle disease, salmonella, and, most recently, avian influenza H5 N1. As migration behaviour changes in European birds as a result of climate change, so will their role as transport agents of organisms that are important to humans.



From Bildstein (2006)

4. IMPACT OF CLIMATE CHANGE IN MIGRATORY BIRDS

Change in the migratory behaviour of wild birds has attracted attention recently, as interest has grown in assessing the effects of human-induced climate change. If weather has become warmer, as it has over much of the world, one might expect birds to have responded accordingly, with migratory species over-wintering at higher latitudes, or arriving earlier and departing later from their breeding grounds. Ring-recoveries, long-term observations of visible migration at migration watchsites, and regional records of first arrival and last departure in spring and autumn, respectively, all have played important roles in assessing the way that bird migration has changed and continues to change over time. The following sections provide examples of these changes.

4.1 Changes in migration timing

Studies of long-term trends in arrival times of birds are mostly based on dates of first sightings, as it is these dates that are most frequently recorded, in some European localities for periods exceeding 300 years (Lehikoinen *et al*. 2004). The problem with first arrival dates is that many refer only to single individuals, which may not be representative of entire populations. Although median or mean arrival dates of populations of individuals in their breeding areas are more representative, they have been recorded less frequently, and chiefly in recent decades. Another source of migration timing are Bird Observatories where observations of visible migrants or trapping dates of other migrants are maintained throughout the migration seasons each year, enabling median or mean passage dates (and standard deviations) to be calculated. One approach in using these data has been to combine records from different Bird Observatories in the same region and calculate regional values.

Whereas arrival (or departure) dates refer to birds from a single population breeding in a particular area, passage dates usually refer to birds from more than one breeding area, occupying a wide span of latitude, counted at a point on their migration. Some studies have compared first and median or mean passage dates from the same site over a period of years, and found the various dates to be correlated (Sparks *et al.* 2005, Hüppop & Hüppop 2003, Jenni & Kéry 2003, Vähätalo *et al*. 2004). In years that were early, the total arrival period was prolonged. Despite methodological differences, long-term studies of migration timing tend to support each other's findings.

SPRING DATES

Presumably as a result of long-term climate warming, many birds now arrive in their breeding areas earlier in spring and depart later in autumn than in the past, spending from a few days to a few weeks longer each year in their summer quarters. Such changes have become apparent in a wide range of species at many localities in both Eurasia and North America (Moritz 1993, Loxton & Sparks 1999, Vogel & Moritz 1995, Sparks 1999, Sparks & Mason 2001, Fiedler 2001, Inouye et al. 2000, Jenkins & Watson 2000, Sokolov 2001, 2006, Sokolov et al. 2000, Bairlein & Winkel 2001, Zalakevicius & Zalakevicuite 2001, Hüppop & Hüppop 2002, Tryjanowski et al. 2002, Bradley et al. 1999, Root et al. 2003, Lehikoinen et al. 2004, Vähätalo et al. 2004, Mills 2005, Stervander et al. 2005). Nevertheless, not all species exhibit such changes. Exceptions may be the result of missing data or population declines that make it more difficult to detect the earliest arrivals and latest departures, as well as inflexibility in migration scheduling, or constancy in limiting factors in spite of climate change.

Of 983 Eurasian bird populations in which first arrival dates on the breeding grounds were monitored over time, 59% showing no significant change, 39% arrived significantly earlier, and only 2% arrived significantly later (Lehikoinen *et al*. 2004). Both short-distance and long-distance migrants showed the same trends. From 222 populations for which mean passage dates could be calculated of time, 69% showed no change, 26% were significantly earlier, and only 5% were significantly later. The average change of first arrival date over all species and sites was -0.373 days per year, while the equivalent figure for mean passage dates was -0.100 days per year. Both figures were statistically significant. It is not obvious why the two figures differed, but in general the mean migration dates were based on larger, more standardised data-sets.

Within the long term trends, arrival and migration dates fluctuated annually in line with local temperature. For example, at the Rybachy Bird Observatory on the Courish Spit in the southeastern Baltic, warming during the 1930s and 1940s, and then in the 1960s and 1980s, was associated with significantly earlier spring migration in many species of song birds, whereas colder periods during the 1950s and 1970s were associated with later passage (Sokolov *et al.* 1998).

Most researchers have used annual temperatures from localities on the migration route or breeding area, whereas others have used the winter-spring index of the North Atlantic Oscillation (NAO), a large-scale climate phenomenon influencing weather in this region (eg Vahatalo et al. 2004, Stervander et al. 2005, Sokolov 2006, Zalekevicius et al. 2006), that is calculated as the difference in normalised monthly values of atmospheric pressure in the Azores and Iceland. Positive values indicate warmer and wetter winter-spring weather (and by earlier spring migration) in northwest Europe and the opposite weather conditions and later arrival dates than usual in southern Europe. Typically, most birds arrived about 2.5-3.3 days earlier for every 1°C increase in spring temperature (based on 203 regression analyses for different Eurasian bird populations, Lehikoinen *et al*. 2004). A smaller number of studies available from North America revealed similar trends (Bradley *et al*. 1999, Inouye *et al.* 2000, Butler 2003, Mills 2005, Murphy-Klaassen *et al*. 2005), although in eastern North America, long-term temperature change has been less marked than in Western Europe. In general, earlier arrival of migrants in spring leads to earlier breeding, as described as a recent trend in a range of species (Crick *et a*l. 1992, Sokolov 2006). Earlier breeding, in turn, often gives rise to higher reproductive success (Thingstand 1997, Sokolov 1999, 2002, Bairlein & Winkel 2001).

Despite strong correlations between arrival dates and temperature on the breeding grounds, much of the variance in arrival dates remains unaccounted for. Migration timing may also be influenced by weather along the migration route or in wintering areas (Sokolov 2006), as well as by changes in weather including wind and barometric pressure, and by different factors such as food-supply. Moreover, poor weather at one part of a migration route can stall migratory movements there, even though conditions may be favourable further along the route. Inter-species differences, which have been demonstrated in every relevant study, could be diet-related, and further investigation is needed.

In comparing the changes that have occurred in the spring migration dates of different species, several general patterns emerge:

- Greater changes have occurred in the migration dates of early-migrating species than of later-migrating species. This is associated with weather (including temperature) being more variable earlier than later in the spring (for passage dates see Sokolov *et al.* 1998, for arrival dates at breeding sites see Slagsvold 1976, Loxton & Sparks 1999).
- Greater changes have occurred in the arrival dates of short-distance than long-distance migrants – presumably because short-distance migrants generally arrive earlier in spring (same point as above), and have more flexibility in their migration timings (Tryjanowski *et al.* 2002, Butler 2003).
- Greater changes have occurred in the arrival dates of smaller bird than larger birds. This is possibly because the smaller species are more sensitive to annual temperature differences and their effects on food-supplies (although their shorter generation times would also favour more rapid genetic change than is not possible in large longer-lived species).
- Inter-annual variability in the arrival dates of short distance migrants generally showed a correlation with spring temperatures in the breeding locality, but such correlations were less obvious in long-distance migrants (Tryjanowski *et al.* 2002). Moreover, where it has been investigated, weather along the migration corridor often shows a better relationship with arrival dates than does weather at the arrival location (e.g. arrival dates of Barn Swallows *Hirundo rustica* in Britain were better related to weather in France-Spain than to weather in Britain, Huin & Sparks 1998).
- Spring weather has not changed everywhere in the same way. Correspondingly, the degree of change in arrival dates in breeding areas varies across Europe, with arrival dates in most areas getting earlier as spring temperatures increase, but later in those areas with decreasing spring temperatures. In the Mediterranean region, springs are now cooler than in the past, which may slowing the return of long-distance migrants from tropical Africa to the mid- and higher latitudes of Europe.
- Most species still arrive on their breeding grounds earlier in warm springs than in cool springs.

Three explanations may account for the fact that more short-distance migrants than long-distance migrants now arrive earlier in spring and in closer correlation to temperatures on breeding areas. First, a stronger endogenous control of migration in long-distance migrants might inhibit a rapid reaction to a changing environment (Gwinner 1986, Berthold 1996). Short-distance migrants are typically more flexible (facultative) in their response, and more able to alter their behaviour in relation to prevailing conditions. Secondly, the closer a species winters to its breeding areas, the more closely correlated are the day-to-day weather changes in the two areas, enabling short-distance migrants to react more rapidly and appropriately. Thirdly, weather is more variable early in the spring, when most short-distance migrants arrive in their breeding areas, than it is later in the spring, when most long-distance migrants arrive.

In most species, males arrive in breeding areas before females, and studies of first arrival dates typically concern only males. But the two sexes may not necessarily respond in the same way to climate change. A long-term study of arrival dates of male and female Barn Swallows *Hirundo rustica* in Denmark revealed that only males responded to climate amelioration during migration (Møller 2004). Therefore, even though males arrived earlier there was change in mean nesting date, because females arrived no earlier than they did 30 years previously.

Earlier arrival on the breeding grounds could be brought about by (a) increases in the speed of spring migration, (b) earlier departure from wintering areas, (c) over-wintering closer to the breeding grounds, or (d) combinations of these possibilities. More rapid progress in warm than cold springs has been recorded in many migrants from the dates they pass through successive observation sites in different years. Only facultative responses could account for the year-to-year variation in arrival dates seen in many migrants, but this need not exclude the possibility of genetic change in response to longer-term environmental trends, such as climate warming. Moreover, a long-distance migrant, the Garden Warbler (*Sylvia borin*), and a short-distant migrant, the Blackcap (*Sylvia atricapilla*) bred in captivity, showed no difference in heritability of migration dates (Pulido 2005).

AUTUMN DATES.

Overall, changes in autumn migration dates over recent decades have been fewer and more variable, than changes in spring dates (Gatter 1992, 2000, Bairlein & Winkel 2001, Sparks & Mason 2001, Jenni & Kéri 2003, Fiedler 2001, Lehikoinen *et al*. 2004, Sokolov 2006; but see Mills 2005). Two patterns have emerged, involving either earlier or later departure over the years. In some single-brooded populations, earlier arrival is followed by earlier breeding and moult, and, subsequently, earlier departure. In such populations, the timing of successive events through the summer, from arrival, egg-laying, hatching, fledging, moult and autumn migration, are correlated with spring temperatures, and show little or no relationship with the prevailing autumn temperature. An earlier spring arrival pulls the whole cycle forward to give an earlier autumn departure (Ellegren 1990, Sokolov *et al*. 1998, Sokolov 2000, 2001, Bojarinova 2002). At Rybachi on the southern Baltic coast, warming in the 1960s and 1980s led to significantly earlier mean dates in spring passage, breeding and autumn passage. Conversely, colder springs during the 1970s caused a shift towards later spring passage, breeding and autumn migration (Sokolov *et al*. 1999). These changes occurred in both short-distance and long-distance migrants. Most migrants at Rybachy came from northern breeding areas that provided time for only one brood.

Similar relationships were found for single-brooded long-distance migrants passing through the Swiss Alps in autumn (Jenni & Kéri 2003). The long-distance migrants may have benefited from an earlier crossing of the Sahara before its seasonal dry period. In contrast, shorter distance migrants passing over the Alps and wintering north of the Sahara mostly showed a later autumn passage. These are mostly passerine species that can raise more than one brood per year, so could better take advantage of a longer season by remaining longer in their breeding areas. Further south and west in Europe, where individuals can make up to two or three breeding attempts in the same season, departure dates of passerines have tended to get later as local temperatures have risen (Marchant 2002), but it is not known whether this has been associated with a lengthening of the breeding season.

4.2 Changes in the length of migration routes

SHORTENING OF MIGRATION ROUTES

So called migration “short-stopping” has occurred in many species as more food has become available at higher latitudes in the wintering range, either through human activities or climate change. Several North American populations of Canada Geese (*Branta Canadensis*) have responded in this way to agricultural changes or to the creation of waterfowl refuges where food is provided (e.g. Terborgh 1989, Hestbeck *et al.* 1991), as have Greylag Geese (*Anser anser*) and Common Cranes (*Grus grus*) in Europe (Rutschke 1990, Alonso *et al*. 1991). Other species of waterfowl have shortened their migrations, apparently in response to warmer winters, as open water has become available nearer the breeding areas. This is manifest by increased numbers wintering in northern and eastern parts of Europe, and declining numbers of the same species wintering in the south and west. Other species of waterfowl have shortened their migrations in apparent response to reduced disturbance and predation, as sanctuaries have been established in areas previously open to hunting.

Examples of migratory short-stopping in raptors include Sharp-shinned Hawks (*Accipiter striatus*) and Merlins (*Falco columbarius*) in parts of North America (Bildstein 2006). For both species an increased dependence upon bird-feeder birds and suburban birds seems to be responsible for the change in migration behaviour.

Shortened migrations are also reflected in the changing distributions of ring recoveries of many other species. Similarly, among 30 species of short-distance or partial migrants breeding in Germany, a tendency towards wintering at higher latitudes was found in ten species, and at lower latitudes in three species, although ringing recoveries are affected by changes in human land use and hunting, as well as in climate (Fiedler *et al*. 2004). More and more European migrants that formerly wintered entirely in tropical and southern Africa are now over-wintering in small but increasing numbers in the Mediterranean. Examples include the Yellow Wagtail (*Motacilla flava*), House Martin (*Delichon urbica*), Osprey (*Pandion haliaetus*), Lesser Kestrel (*Falco naumanni*), and White Stork (*Ciconia ciconia*) (Berthold 2001).

In some regions irruptive migrations have become less frequent than formerly, presumably because the birds have become less numerous or, more often, remain in their breeding areas year-round. Comparing the nineteenth with the twentieth centuries, the Pine Grosbeak (*Pinicola enucleator*) has become a much less frequent visitor to the middle latitudes of Europe. No noticeable invasions of Scandinavian Great Tits (*Parus major*) and Blue Tits (*Parus caeruleus*) to Britain have occurred since 1977 and no big invasions of Great Spotted Woodpeckers (*Dendrocopos major*) since 1974. In Germany, invasions of Blue Tits, Waxwings (*Bombicilla garrulous*) and Redpolls (*Carduelis flammea*) have also become less frequent (Fiedler 2003). On the other hand, Two-barred Crossbills (*Loxia leucoptera*) have appeared in Fennoscandia in increasing numbers and frequency, possibly associated with the increased planting of larch (*Larix* spp.) outside their natural range. Likewise, in eastern North America, Evening Grosbeaks (*Hesperiphona vespertina*) have become less numerous, and their invasions less frequent, than previously. This may be associated with reduced outbreaks of Spruce Budworm (*Choristoneura fumiferana*), a favoured summer food, and with increased winter bird feeding by householders.

Other types of change have also occurred. For example, like many other birds that does not start to breed until they are two or more years old, young White Storks (*Ciconia ciconia*) remain in “winter quarters” through their first summer, or migrate only part way towards breeding areas. In recent decades, second-summer birds, whose predecessors used to remain in Africa, have returned in increasing numbers to southern Europe to pass the summer. The mean distance of recoveries of second-summer birds from their natal sites in north Germany was 2,517 km in 1923-75 (N = 120), reducing to 720 km in 1978-96 (Fiedler 2001).

LENGTHENING OF MIGRATION ROUTES

In species that have expanded their breeding areas to higher latitudes yet have retained the same wintering areas, extension of migration routes has occurred. Northern hemisphere examples include: (1) Black-winged Stilt (*Himantopus himantopus*) which is expanding its breeding range northward (France, Ukraine, Russia) but still winters south of 40°N latitude; (2) European Bee-eater (*Merops* *apiaster*) which has expanded northwards in almost all central European countries, yet still winters entirely in Africa south of the Sahara; (3) Citrine Wagtail (*Motacilla citreola*) which is expanding its breeding range from Asia westward into Europe, but still winters in India and southeast Asia (Fieldler 2003). The intra-European routes have increased by up to 1,000 km. These examples represent the kind of changes that must have occurred in many species after each glaciation, when ice receded, and plants and animals spread from lower to higher latitudes.

Most Red-breasted Goose (*Branta ruficollis*) now over-winter in Romania-Bulgaria, some 300-600 km further from their breeding areas than in the 1950s, as former wintering sites in Azerbaijan have been altered by land-use changes (Sutherland & Crockford 1993). In even earlier times, the species was found in winter even further from its breeding areas, being depicted in the art of ancient Egypt (Houlihan 1986). Thus over recorded history this species has both shortened and lengthened its migration routes. Such changes in the length of migrations could initially involve only facultative responses to local conditions, but as migrations lengthen over time, some genetic change seems likely, as they would require changes to regulatory mechanisms.

In some other species, greater proportions of ring recoveries are now being obtained from the distant parts of migration routes than formerly, but it is hard to tell whether this is due to altered migration behaviour, or to increased opportunities for recoveries along the routes (Fiedler *et al.* 2004). In particular, over recent decades hunting has declined much more in the northern and mid latitudes of Europe than further south. This could affect the migratory behaviour of hunted species, or the distribution of their ring recoveries.

4.3 Changes in migratory habits

MIGRATORY TO SEDENTARY

At many latitudes many populations of birds have become more sedentary recently. For example, prior to 1940, the Lesser Black-backed Gull (*Larus fuscus*) was almost entirely migratory in Britain, with only a few individuals remaining year-round. Today, large numbers of all age-groups stay for the winter, feeding mainly on refuse dumps which have increased the winter food-supply (Hickling 1984). A similar change has occurred among Herring Gulls *Larus argentatus* in Denmark (Petersen 1984). Another example is the Eurasian Blackbird *Turdus merula*, in which the British and mid European populations have become progressively more sedentary during the last two centuries, as winters have mellowed (Berthold 1990, Main 2000). In both Europe and North America, many seed-eaters are now wintering further north in their breeding range, in association with the provision of suitable food at garden feeders. Winter feeding turned a Great Tit *Parus major* population from migratory to sedentary in the Finnish city of Oulo near the Arctic Circle (Orell & Ojanen 1979). Among many other short-distance and medium-distance migrants, increasing numbers of individuals now winter in areas where they once were wholly migratory, these species developing into typical partial migrants. Some such changes could be genetic in nature, others facultative. Their net effect is to expand the winter avifauna of many high-latitude areas.

SEDENTARY TO MIGRATORY

Examples of changes from sedentary to migratory behaviour are less evident, and are generally associated with an extension of breeding range into higher latitudes. For example, the European Serin (*Serinus serinus*) was once restricted to the south of Europe where it is sedentary, but in the early 20th century it spread north, where it became migratory. In more recent years, with milder winters, this migratory population has become partially resident (Berthold 1999). Likewise, since the 19th century, many bird species have spread north in Fenno-Scandia, including the Northern Lapwing (*Vanellus vanellus*), Starling (*Sturnus vulgaris*), Eurasian Blackbird (*Turdus merula*) and Dunnock (*Prunella modularis*). In newly colonised breeding areas they are essentially migratory, whereas further south they are partial migrants or sedentary (Schüz *et al.* 1971).

CHANGES IN MIGRATORY DIRECTIONS

A well known example of recent change in migratory direction involves the Blackcap (*Sylvia atricapilla*), a species that is now wintering in increasing numbers in the British Islands. Changes in the direction of migration, leading to the adoption of new wintering areas, also were recorded in several species in the last century. For example, Little Egrets (*Egretta garzetta*) breeding in southern France migrated southward, some crossing the Sahara to winter in the Afrotropics. Beginning in the 1970s, increasing numbers began to migrate northwest to winter in northern France, southern Britain and Ireland (Marion et al. 2000). Some later became resident in these areas, and from the 1990s started to breed there. Similarly, Lesser Black-backed Gulls (*Larus fuscus*) from Europe have begun increasingly to winter on the coasts of eastern North America, with records from Nova Scotia to Florida, a change which requires a much stronger westerly component in the directional preferences. Almost certainly, such marked directional changes have involved genetic changes, as confirmed for the Blackcap by breeding and direction-testing in captivity.

A different type of change is shown by those northern hemisphere species introduced to the southern hemisphere, which have reversed the direction of their spring and autumn journeys, respectively, so that they continue to winter in lower rather than in higher latitudes. This is true, for example, for the European Goldfinch (*Carduelis carduelis*) and others introduced from Europe to New Zealand in the 19th century, and also for the White Stork (*Ciconia ciconia*) which colonised South Africa naturally in the 1930s, and now migrates north to over-winter in Zaire and Rwanda (Harrison et al. 1997).

4.4 Discussion

Most of the work cited in this report focuses on particular species or suites of similar species, and it is difficult to determine what proportion of an avifauna's migration habits, other than arrival times, have changed in recent decades. Over the past 50 years, climate changes have been more marked in some regions than in others, and studies reporting changes in migratory behaviour were more likely to be published than those finding no change. However, among the bird species that breed in Britain, 73 provided enough ring recoveries from a sufficiently long period to look for changes in the lengths and directions of migratory movements. Of these, 51 (70%) of these species showed no significant change in either respect during the 20th Century, in 15 species movements became shorter, in five species they had become longer, and in two species movements changed in complex ways. The 22 species that evidenced change were significantly more than the four expected on a significance level of 5%. These species included song birds, raptors, waders, waterfowl, and seabirds (G. Siriwardena & C. Wernham, in Wernham *et al.* 2002). Similarly, of 30 species that breed in Germany, and provide enough ring recoveries, eight species showed decreasing mean recovery distances with time, whereas five species showed increasing mean recovery distances (Fiedler *et al* 2004). Again the numbers that showed change were significantly greater than the two expected at a significance level of 5%. Such studies confirm that changes in the migration behaviour of birds have been common over the last several decades.

These observations, together with selection experiments on captive birds, serve to confirm that migration is a dynamic phenomenon, subject to continual change in response to prevailing conditions. Some aspects, such as an abrupt change in the direction of migration, imply rapid evolutionary shifts, whereas may represent either genetic or facultative responses to changing conditions. Overall, it seems reasonable to assume that both genetic and facultative responses are likely to be involved, with birds responding initially by facultative means, and, eventually, genetically, as natural selection comes into play. Facultative responses are relatively limited (though variable in extent between species), and if environmental conditions continue to change in the same direction, such responses eventually become inadequate to deal with the new conditions. Only genetic change may enable the population to respond appropriately to conditions beyond the previous range.

Although all major aspects of migratory behaviour have been shown to have heritable components, mainly through artificial selection and cross-breeding in captivity, genetic change is not easily demonstrated in wild populations. The assumption is that, if individuals taken from the wild in different years or from different regions express behavioural differences when held under identical controlled conditions, these differences are likely to have a genetic basis. This conclusion is strengthened if the trend is maintained in captive-bred offspring from these individuals, unaffected by parental effects or experience in the wild. Such a test has been made with Blackcaps (*Sylvia atricapilla*) randomly collected as nestlings from south Germany and hand-raised each year over a 13- year period (Berthold 1998, Berthold & Pulido 2003). In successive samples of birds, the amount of autumn migratory activity was found to decline, towards a later onset and reduced intensity (less activity per night). This was precisely the result expected if the population had responded genetically to ameliorating environmental conditions, so at least in this species later departure and shorter migration may partly represent a genetic response resulting from natural selection.

Occasionally, a wild population under study has unexpectedly provided evidence for genetic change in some aspect of migration, as in the effect of unusually severe weather on the arrival and departure dates of the swallows. Indications of genetic change in other aspects of migratory behaviour also can be gained from long-term studies of wild bird populations, but these studies are not without problems, and findings can often be interpreted in different ways. Moreover, apart from arrival dates, reliable information on migratory traits is hard to collect from free-living birds (Pulido & Berthold 2004).

In any population the rate of evolutionary change is limited by: (1) the amount of genetic variation within the population at the time; (2) the strength and consistency of the selection pressure; and (3) the extent to which selection on one trait causes parallel changes in others, which could be beneficial or detrimental. Genetic variance is often reduced in populations that have suffered recent numerical declines in which much of the variance was lost (genetic bottlenecks). Such variance can be increased again by immigration and gene flow from another population, or in the longer term by mutation and other means. Immigration can also have deleterious effects if it breaks up locally-adapted gene complexes, and makes the local population less well adapted to local conditions.

Single selection events, such as spring storms, can cause rapid genetic change in the arrival dates of populations, but reversed selection pressures could rapidly reverse the situation, and change arrival dates back to their original state. Selection pressures must act consistently in the same direction over several generations if they are to have any more than temporary effects on the genetic composition of a population. Most selection probably acts to stabilise the gene pools of populations rather than to change them. Moreover, most migratory traits (notably incidence, intensity and timing) are part of a syndrome of co-adapted traits (Pulido & Berthold 2003), so selection on one trait is likely to have strong simultaneous effects on the others. If this is disadvantageous in the new conditions, it may take many generations of selection to dissociate the beneficial traits from the detrimental ones before evolutionary change can occur. Evolutionary change may thus be rapid or slow, depending on the circumstances.

An important aspect of global warming is that temperatures have increased more in some regions than others, and more at some times of year than others. The timing of spring migration could be influenced by weather conditions along the whole migration route, whereas the timing of egg-laying depends of conditions on breeding areas. Any discrepancy between conditions en route and in breeding area can worsen the mismatch between breeding and food supply. Moreover, in the breeding areas themselves, birds may respond more or less rapidly than their food organisms to climatic changes, so that birds cease to arrive and breed at the optimal time. An apparent example is provided by Pied Flycatchers (*Ficedula hypoleuca*) breeding in the Netherlands, where climate change has advanced the food supply on which breeding depends, but spring migration has not advanced sufficiently to allow the birds to make best use of this food supply, as they did in the past (Both & Visser 2001). The birds thereby suffered reduced breeding success, and in areas with the biggest “ecological mismatch,” population levels declined by about 90% over a 20-year period (Both et al. 2006). Such mismatches can only be rectified in the long term by changes in the genetic controlling mechanism, so that migration is triggered at an earlier date with respect to prevailing conditions. The longer the migratory journey, the less likely is weather in the breeding and wintering areas to be correlated. Long-distance migrants would have little if any indication on their wintering areas regarding how spring is developing on the breeding ground. Their departure dates from wintering areas are triggered by a photo-periodically timed endogenous rhythm, evolved through natural selection, which ensures that they arrive on breeding areas at an appropriate date (with minor variation according to prevailing conditions). Only by evolution acting on this endogenous control mechanism is the trigger date for departure likely to be changed. In this situation, the selection pressure to migrate earlier is applied in the breeding area, but the action to accomplish an earlier arrival occurs weeks before in the wintering area, hundreds or thousands of kilometres away (Visser *et al*. 2004). Changing this control mechanism may be a relatively slow process, perhaps explaining why the arrival dates of long-distance migrants are less well correlated with temperatures on breeding areas than are the arrival dates of short-distance migrants, wintering nearer to breeding areas. Another mismatch was found in the American Robins (*Turdus migratorius*) that breed at high elevations in the Rocky Mountains of Colorado and whose spring arrival dates advanced by two weeks over a 20-year period. At the same time, winter snow-fall increased and took longer to melt, producing a mismatch between arrival dates and the exposure of bare ground feeding areas (Inouye *et al.* 2000).

These examples raise the general point that the photoperiodic responses of many birds, through which their annual cycles are often timed, may become less reliable predictors of seasonal change in food supplies, as climate change alters the phenology of their food supplies. This is not a new problem, as it is faced by all birds as they expand their breeding ranges into different regions, but it will take time for them to adjust genetically to new situations, during which time they could perform less well than usual (though not necessarily with effects on population levels).

5. RECENT CHANGES IN THE DISTRIBUTION OF BIRDS

During the last 150 years, the annual average temperature in many places of the northern hemisphere increased by as much as a few degrees centigrade, and the May-June isotherms moved up to several hundred kilometres northwards and up to several hundred metres up mountainsides. Over the same period many mid-latitude birds species increased and spread northwards, while other more northern species declined and retreated yet further north. Such range changes usually have been attributed to climate change (Burton 1995), but often without considering the possible effects of other potential causes as human impacts on habitat, changes in the public perception of birds, change in food-supplies or available nest sites, etc. Hence, some of the changes may well have been due to a combination of climate change and other factors. Almost always, uncertainty hangs over any explanation based on correlative analyses (Newton 2003).

That said climatic change as an explanation of changes in ranges of birds is based on two things. First that many of the changes are latitudinal (i.e., towards the north in the northern hemisphere), and second that for many species of birds reproductive and survival rates are clearly influenced by weather (Newton 1998). Hence, resident birds that suffer high mortality in hard winters, for example, might be expected to increase and spread further north during a run of mild winters. Some might then compete with more northern species, causing them to retreat even further north.

During the twentieth century, major northward expansions in Europe occurred in the Grey heron (*Ardea cinerea*), Lapwing (*Vanellus vanellus*), Common Starling (*Sturnus vulgaris*), Wood-pigeon (*Columba palumbus*), Rook (*Corvus furgileus*) and Tawny Owl (*Strix aluco*). In some pairs of closely related species, as the southern form pushed northwards, its northern counterpart retreated. This occurred in both the Chaffinch (*Fringilla coelebs*) and the Brambling (*F. montifringilla*). In total, 39 species of European landbirds have clearly expanded their ranges toward north during the 2oth Century (Newton 2003).

6. CONSEQUENCES OF THESE CHANGES

Generally, warmer climates would lead to an increase in the number of residents populations in Europe, first as already sedentary populations in crease, second as obligate and facultative partial migrants become more sedentary, and third, to a limited extent, as some populations of complete migrants also become sedentary. At the same time, long-distance migrants would shorten their migratory movements. As a consequence of such changes the phenomenon of migration, itself, would be at risk. Specific predictions include:

- Greater survivorship among resident populations in high-latitude areas.
- Increased competition between long-distance migrants and residents on the breeding grounds.
- Increasing risk of ecological mismatches between migratory birds and their food-supplies more probable among long-distance migrants.
- Changes to migratory directions and the choice of new, closer winter quarters.
- A reduction in the migratory distance to the winter quarters,
- Increasingly delayed departure times.

- Earlier return times.
- A substantial shift away from migratory behavior, particularly long-distance migration, including a reduction in large-scale movements along well-established thermal corridors.

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7. OTHER RELATED IMPACTS

Migratory birds are sometimes killed in large numbers by storms encountered when they are migrating. Climatologists predict that, in many regions, storms and other extreme events are likely to increase in severity and frequency in the future. We can expect, therefore, that migrants will suffer greater weather-induced losses, which could cause noticeable reductions in their populations, regardless of other changes.

Climate change is not the only potential risk for migratory birds. Several well-described impacts of habitat manipulations and infrastructures are now negatively affecting populations of birds and their impacts may be additive to those of climate change. Included among them are power lines and wind farms that offer potential and real hazards for several migratory birds.

Collision with power lines is considered to be an important death cause for some bird species (Crivelli *et al.* 1988, Fiedler & Wissner 1980, Morkill & Anderson 1991). For most species involved in collisions, however, death rates at the population level are low (Brown 1993, Hugie et al. 1993). Most publications about collision of birds with electric wires focus on transmission lines (from 220 kV to higher tension) and, specifically on ground wire (static wire) collisions (Beaulaurier 1981, Faanes 1987, Heijnis 1980).

Non-conducting static wires are usually installed in transmission lines above the conductor wires to intercept lightning strikes and prevent power outages. They are generally smaller in diameter than the conductor wires. Consequently, according to some authors, birds often see and avoid the conductor wires only to strike the less visible static wire. Ground wires are believed to cause most of the collisions (Faanes 1987), and many different methods have been used in attempts to diminish mortality by such collisions including marking ground wires (Alonso et al. 1994, Beaulaurier 1981, Faanes 1987, Heijnis 1980, Miller 1993, Morkill & Anderson 1991). The attention given on ground wire marking has created the general idea that only transmission lines are important obstacles for birds, and not the much more abundant distribution lines (usually without ground wires), with a tension lower than 220 kV. Varying success is obtained with ground wire marking, but over the years various solutions have been published and one might expect that nature managers have access to those solutions.

Another type of accidents involving power lines is electrocution when the bird make contact with the wire while perching on conductive pylon. Electrocution from electric power lines carrying a current of between 16 and 45 Kv was described as the major risk factor for several populations of raptors (Ferrer & de la Riva 1987, Negro 1987, Ferrer et al. 1991, Ferrer 2001) including the endangered Spanish Imperial Eeagle (*Aquila adalberti*) during the 1980s and 1990s (Ferrer 2001), accounting for 46% of all adult deaths and 40% of all immature deaths in this species.

In Spain, regulatory and technical solutions largely solved this problem in the 1990s (Ferrer & Janss 1999), and today a significant reduction in deaths due to powerline collisions is evident (i.e., >84% reduction in collisions involving Spanish Imperial Eagles, Ferrer & Penteriani 2007). Regretfully, not all the members of Council of Europe have adopted similar regulations regarding new powerlines and retrofitting particularly dangerous existing lines.

Some measures taken to reduce climate change, including the development of wind farms, could, themselves, severely impact migratory birds. Despite the obvious benefit of wind turbines as a clean energy source, it is known that wind farms can potentially have adverse effects on birds, notably fatality through collision with rotating turbine rotor blades (e.g. Langston and Pullan 2003). This is particularly so if wind farms are improperly sited along major migration routes, where large numbers of migrants could then be destroyed via collisions with the rotor blades. The use of wind as a renewable energy source has been increasing in many countries. At the current level of development, wind turbines have been estimated to comprise less than 0.01% of the total annual avian mortality from human-caused sources in the USA (Erickson, 2002). Although such analyses do not acknowledge that some bird species may potentially be affected more by wind turbines than other anthropogenic mortality sources, at least one study has concluded that wind turbines, when properly sited, can have minimal impact in comparison with other factors (Fielding et al. 2006). Nevertheless, the potential for wind farms to cause problems for bird populations should not be underestimated (Hunt 2002), so the coexistence of birds and wind farms would be enhanced by a more detailed approach to this conservation issue and a greater understanding of the factors involved in influencing collision fatality (Barrios and Rodríguez 2004, De Lucas, Janss & Ferrer 2007). Fortunately, we now have more scientific information about factors affecting bird mortality in wind farms as well as predictive methods to avoid dangerous locations for these wind turbines (De Lucas 2007). Again a European directive would be welcome.

8. LONG-DISTANCE MIGRATION AND BIRD BIODIVERSITY

The long-distance movements of birds may have important implications in avian speciation and, in turn avian diversity. As we stated above, one of the likely responses to global climate change in birds is a substantial shift away from migratory behavior, particularly long-distance migration, including a reduction in large-scale movements along well-established thermal corridors.

This then begs the question: What might be the consequences of the loss of long-distance, trans-equatorial bird migration? One of the unintended consequences of millions of birds flying long distances into, out of, and within the tropics each year is that a small but significant portion of the migrants get lost. Approximately half of all migrants in autumn are juveniles, and this inexperienced age class is particularly likely to become disoriented or wind drifted during migration. This results in the phenomenon of avian vagrancy. “Vagrants” are members of a species that appear from time to time in geographic areas where they do not regularly breed, over-winter, or migrate through. Although relatively uncommon, vagrancy is an inevitable consequence of long-distance migration. The extent to which vagrancy occurs is evidenced by the fact that more than one third of all bird species on the northern California bird list are vagrants, as are more than 50% of those on the British bird list.

Vagrancy, in turn, can result, in “migration dosing,” in which flocks of migrants simultaneously arrive at sites tangential or beyond traditional wintering areas, and consequentially fail to return to their intended destinations the next spring. Although most of these vagrants die before breeding, in some instances they eventually breed in the new location and, over time, either by random genetic drift, natural selection, or both, eventually diverge from their parental stock and develop into a new species.

An extreme case of migration dosing can be found in the South Pacific accipiters, a species group of bird-eating raptors that is believed to have first evolved in Asia. One particularly migratory representative of this genus is the exceptionally long- and pointed-winged Chinese goshawk (*Accipiter soloensis*), which each autumn travels along the East-Asian Oceanic Flyway from breeding areas in eastern Asia to the South Pacific islands of the Philippines and Indonesia. In El Nino years, “migration overshoots” by this species create opportunities for migration dosing east of Wallace’s Line in Wallacea, when groups of this migrant fly beyond their normal wintering areas, land on isolated in the region and subsequently breed and speciate there. Another example of migration dosing involves the Swainson’s Hawk, a long-distance, North America migratory raptor that has given rise to both the Hawaiian Hawk and Galapagos Hawk via this speciation process. Although the extent to which migration dosing contributes to avian diversity overall remains unclear, it is clear long-distance migration sometimes acts as an engine of biodiversity, and as such merits protection in its own right.

9. CONSERVATION IN PROTECTED NETWORKS. IT IS ENOUGH?

The establishment of protected areas has been the core aspect of conservation action throughout the world. Initial actions to preserve nature have included the creation of national parks, reserves, and sanctuaries. A principal assumption of this action was that nature conservation was incompatible with human use and, sometimes, even human presence. From a scientific point of view, it is clear that this approach was necessary, especially during the first half of the past century, when human attitudes toward biodiversity were incomplete and wholesale transformation of natural landscapes was underway. Since then island biogeography theory and metapopulation models, among others, have resulted in a better appreciation for the importance of ecologically-based reserve design that takes into account minimal areas and connectivity needed to sustain viable populations of species. As a result, individual states and groups of states have begun to develop networks of reserves, which together can function to reduce the risk of regional extirpation. Examples include the European Union's Natura 2000 Network.

That said there are relatively few examples of truly biologically functional networks of protected areas. This, together with the fact that climate models now suggest that significant fractions of the plant and animals we are now trying to protect inside existing Natural Park networks are going to be out of them in a few decades, suggests that fundamental shift in reserve and network design is needed. Simply put if the existing components of biodiversity are to be preserved, a more flexible reserve system compatible with human activities that promotes public participation and is complementary to the Natural park network is needed. It is time to think about these new opportunities and obligations.

10. TOWARD ADAPTIVE MANAGEMENT

If existing natural park networks are not enough what can we do to preserve bird biodiversity in the face of Global Change? Now is the time to change our conservation policies. Obviously we don't have a definitive answer but we do offer several suggestions.

10.1 Establish a surveillance network for migratory fauna at continental scale

Birds are wonderful indicators of biodiversity and environmental change, including climate change. They are popular in Europe among birdwatchers, amateur naturalists, and professional scientists, and there are rich sources of long-term data regarding their abundances and distributions. As such they are perfect environmental sentinels of climate change. Their populations and, in particular their migratory populations, should be monitored in the face of global climate change. This is especially so at important regional and continental bottlenecks. We recommend selecting several sites as the basis for a functional network of migration "watchtowers" for monitoring changes in migration behaviour and populations of migratory birds in Europe. Especially we suggest the following sites:

- The Strait of Gibraltar near Tarifa, Spain
- Falsterbö in south-western Sweden
- Elat in southern Israel
- Fair Isle in northern Scotland
- Texel in north-western Holland
- South of Italy, including the Strait of Messina

Most of these sites already are conducting long-term monitoring programs that started in the middle of 20th Century. These monitoring programs should continue and efforts should be made to collect and analyze data using a common protocol so that direct, inter-site comparisons are possible. International coordination is needed to accomplish this. At the same time these sites can work locally to introduce and build support among regional populations for charismatic migratory birds, which can then become flagships for broader conservation issues.

The above-mentioned watch sites are the minimum necessary to start. Obviously, as number of observatories in the network increases the quality of the information also increase. Therefore, the network must be open, free and constituted by independent watch sites, ideally as much as possible.

In addition to developing a network of watchsites, we also need to agree upon a set of representative species to be monitored. These species should chosen on the basis of their utility as indicators of more difficult to follow but highly significant biological variables, including total biodiversity, and early warning signals of loss of specific critical habitats. Specifically we recommend including:

Raptors and other soaring birds

Among birds, raptors are one of the best indicators of biodiversity, including also additional features such a long historical data series, a generally well known ecology, an easy detection and identification, a high level in trophic chains and a big size that make possible the use of a large set of technology difficult to use in smaller birds. Some raptor species are good examples of mountain fauna such as Golden Eagles (*Aquila chrysaetos*) or Bonelli's Eagles (*Hieraaetus fasciatus*), a habitat under risk with the increasing temperatures. Some raptors feed on my types of prey, whereas others specialize on certain taxonomic groups. For example the Short-toed Eagle (*Circaetus gallicus*) feeds largely on reptiles Raptors include many insectivorous species including small falcons and owls, bird-eating species including large falcons and accipiters, mammals-eating species including hawks, eagles, and owls), and carrion-eating species including vultures and kites. So, a broad number of different aspects would be followed using raptors as indicators. Some other species of soaring birds such as storks and cranes would be included.

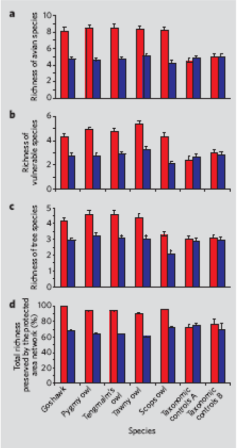

Figure 1 | Biodiversity estimates are higher at sites occupied by five top predators than at randomly selected sites or at sites occupied by species from lower trophic levels (taxonomic controls). Red bars, breeding sites; blue bars, randomly selected spatial-control sites. Values represent averages ± 1 s.e. **a,** Numbers of all avia species. **b,** Numbers of avian species classified as vulnerable. **c,** Numbers of tree species. **d,** Percentage of maximum attainable avian-species richness in a hypothetical system of protected areas, as estimated by gap analysis[7,8].

Figure from Sergio *et al.* (2005) showing the relationship between raptor community and biodiversity at different taxonomical levels.

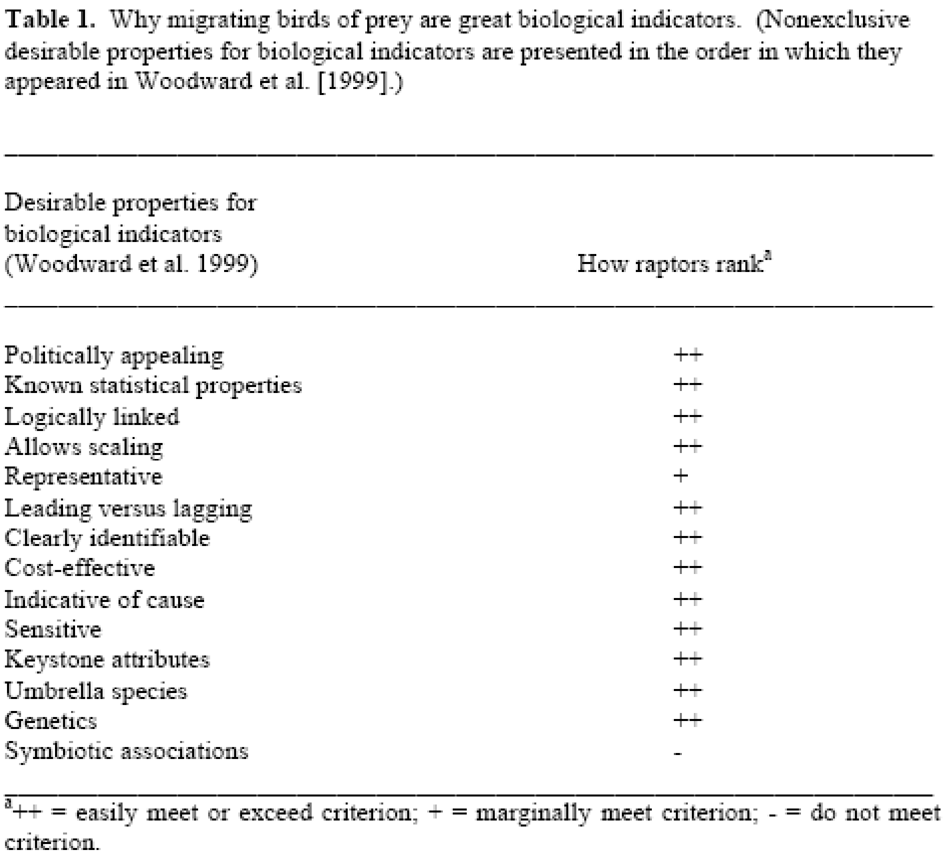

Table 1. Why migrating birds of prey are great biological indicators. (Nonexclusive desirable properties for biological indicators are presented in the order in which they appeared in Woodward et al. [1999].)

Desirable properties for biological indicators (Woodward et al. 1999)	How raptors rank[a]
Politically appealing	++
Known statistical properties	++
Logically linked	++
Allows scaling	++
Representative	+
Leading versus lagging	++
Clearly identifiable	++
Cost-effective	++
Indicative of cause	++
Sensitive	++
Keystone attributes	++
Umbrella species	++
Genetics	++
Symbiotic associations	-

[a] ++ = easily meet or exceed criterion; + = marginally meet criterion; - = do not meet criterion.

From Bildstein (2001)

Aquatic birds

Aquatic birds should be included since they depend upon wetlands changes to which are expected to occur as a result of climate change. So, several changes are expected in relation to abundance and distribution of waterfowl and waders. As in raptors, aquatic species have been object of major attention by ornithologists and scientists for some time and we now possess long datasets regarding their distributions and abundances changes. Examples of aquatic birds that should be monitored include the Greylag Goose (*Anser anser*) and the Ruff (*Philomachus pugnax*),

Seabirds

Because climate change is expected to affect sea levels especially in the Mediterranean basin, monitoring seabird species is highly recommended. Actually there are several programs following migration in this group of birds that must be maintained and coordinated at continental scale.

Songbirds

There is a long tradition of work on song birds throughout Europe. Different species of song birds depend upon different habitats and prey bases and 4-6 species of these birds should be identified for focused monitoring.

To be effective, all these monitoring efforts, and the resulting data, must be communicate to the scientific community for their use and research, providing a good way to interchange new findings. The recent experience in the first international meeting on Bird Migration and Global Change, hosted in Algeciras (Spain, 2007), indicates the value of regularly scheduled international meetings to favour the interchange of new ideas and recent findings, as well as to coordinate monitoring efforts.

10.2 A new dynamic system of protected areas

The establishment of protected areas has been the core aspect of conservation action for some time. European Union implemented also the Natura 2000 Network. This approach, while important and necessary is insufficient to prevent loss of biodiversity that is moving across the continent. It is time to think about other complementary possibilities.

Additionally to the Natura 2000 network, we recommend land custody or stewardship in the form kind of private voluntary agreements between landowners and a custody or stewardship agent (usually a non-profit organization) who decide to collaborate in protecting biodiversity and land use through economic incentives for the land owner. Land custody provides a more flexible approach to biodiversity protection across a climatically changing than does a more static network of government-owned protected areas, and also increases a sense of public owner for the underlying natural resource. One option for increasing public interest in land custody would be to couple participation with tax incentives for land owners.

In 1991, the Standing Committee of the Council of Europe adopted a recommendation (nº 25) on the conservation of natural areas outside protected areas proper. The recommendation indicates that that certain forms of action including land custody have proved particularly effective in the countries where they have been adopted and that flora and fauna conservation is possible only in the context of a regional planning policy conserving their environments and habitats, and goes on to encourage the granting of tax concessions to owners who comply with these objectives. Unfortunately there is no common policy for carrying this out.

A second recommendation is to investigate the use of linear infrastructures including power-line, road, railway rights-of-ways as a supplementary wildlife corridors, after adequate interventions. A working example of this approach involves REE, the main transporter of electrical power in Spain, which is now supporting an experimental project to create micro-islands under electric power-lines to increases local biodiversity and to create a net of ecological “stepping stones” across the country. The same idea could be applied to road and railway rights-of-ways, and to coastlines, which also could serve as movement corridors for plants and animals during periods of climate change.

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