A Climate Risk Report

Bird Species and Climate Change

The Global Status Report: A synthesis of current scientific understanding of anthropogenic climate change impacts on global bird species now, and projected future effects.

Climate Risk Pty Ltd are specialist advisors to business and government on risk, opportunity and adaptation to climate change.
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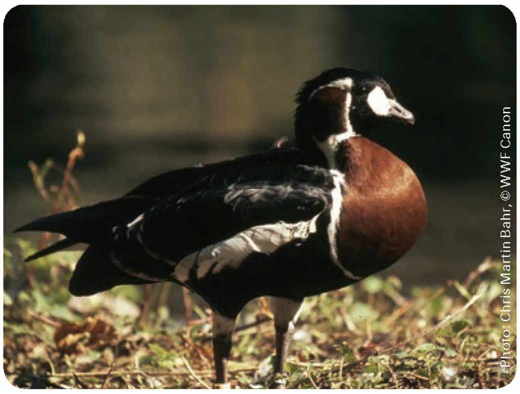
1.0 Introduction

"Climate change is emerging as the greatest threat to natural communities in many, if not most, of the world's ecosystems in coming decades, with mid-range climate change scenarios expected to produce greater extinction rates than habitat loss, currently deemed the top threat to biodiversity" (Thomas *et al.*, 2004; Malcolm *et al.*, 2006).

More is known about birds' response to climate change to date than for any other animal group, mostly as a result of many species- and location-specific analyses. Yet of the global or international-scale analyses of biodiversity and climate change, very few concentrate on birds in particular. This review seeks to provide a global survey of the climate threat to birds by compiling hundreds of individual studies to resolve the larger picture of impacts.

This analysis finds compelling evidence that, with 0.8 °C (Hansen *et al.*, 2005) of warming having occurred over the past century, strong negative impacts on birds are already taking place. Climate change is affecting birds' behaviour, distribution and population dynamics, and is implicated in complete breeding failure in some populations. The majority of evidence indicates that continuing and expected changes to the climate of 1.4 to 5.8°C by 2100 (IPCC, 2001a; a projection expected to be revised to 2.0 to 4.5°C under a scenario of a doubling of CO_2 in the United Nations' upcoming Fourth Assessment Report [Giles, 2006]) will have very serious effects on birds, including huge shifts in distributions, major population declines and high levels of extinction.



At high risk from climate change: the red-breasted goose

2 How climate change can act on birds

Highly sensitive to climate and weather, birds are pioneer indicators of climate change (Berthold *et al.*, 2004), the quintessential "canaries in the coal mine." As global warming brings changes in temperature, altered moisture and precipitation, more extreme weather and a generally more variable climate, birds from the Arctic to Antarctic are already responding.

In future, global warming will also affect birds indirectly through sea level rise, changes in fire regimes, vegetation changes and land use change. With a doubling of atmospheric CO_2, climate change could eventually destroy or fundamentally alter 35 per cent of the world's existing land habitats (WWF, 2000).

In the Arctic, where several hundred million migratory birds breed, a doubling of CO_2 suggests the loss of almost half the breeding grounds of 10.4 million geese and 14.5 million waders by 2080-2099. Some Arctic birds will lose more than 90 per cent of their habitat at higher levels of warming (Zöckler and Lysenko, 2000).[1] In Europe, Mediterranean coastal wetlands, which are critical habitat for migratory birds, could be completely destroyed with 1.5 to 4.2°C of warming by the 2080s (IPCC 2001b).

Climate change will also cause some of its most serious but least predictable impacts by shifting the timing of natural events and by shifting species' geographical distributions. This will re-arrange plant and animal communities and ecosystems, and disrupt birds' relationships with predators, competitors, prey and parasites. These changes are expected to alter the makeup and functioning of most, if not all, the world's ecosystems (Root and Hughes, 2005). Evidence suggests many bird species will not be able to adapt.

3 The effects of climate change on birds

3.1 Shifts in timing

The early warning signs of climate change can be seen in shifts in timing of important seasonal events for birds, such as egg laying and migration. These shifts have been documented in North America, Australia and Europe. Some birds in Europe have even stopped migrating altogether with climate warming (Lehikoinen *et al.*, 2004).

These timing shifts are a threat when they force birds' life cycles out of synchrony with plants and insects upon which they depend. In Europe, some populations of pied flycatchers, which are long-distance migratory birds, have suffered a 90 per cent decline in numbers over the past two decades, an effect strongly linked to their failure to keep pace with climate change. With their insect prey numbers peaking earlier due to warming, but their migration timing unchanged, they no longer arrive at their breeding grounds in time to match peak food supply with peak nestling demands (Both *et al.*, 2006).

Thus climatically-forced shifts can harm birds' reproductive success and survival, and could even contribute to the collapse of breeding populations over the long term (Sanz *et al.*, 2003). The mismatch puts serious additional pressure on long-distance migrant birds, which are vulnerable to the summed climatic risk for each habitat used along their migration path (Huntley *et al.*, 2006). Of 119 long-distance migrants studied in Europe, 54 per cent have already shown a sustained, often severe, decline from 1970 to 2000, with climate change implicated as a major contributing factor (Sanderson *et al.*, 2006).

3.2 Shifting and shrinking ranges

There is compelling evidence that birds, along with other animals and plants, are already shifting their ranges in response to climate change (Parmesan and Yohe, 2003). Importantly, although range changes will vary for different species,

1. UKMO climate model; a rise of 5°C at the time of a doubling of CO_2 by the period 2070-2099.

range contractions are expected to be more frequent than range expansions (Huntley *et al.* 2006; Böhning-Gaese and Lemoine, 2004; Erasmus *et al.*, 2002). Range shifts pose major threats to birds, both directly and indirectly.

3.2.1 Direct effects of altered ranges

Bird species are already shifting their range boundaries pole-ward (IPCC, 2001b; Pounds *et al.*, 1999) and some tropical mountain birds are shifting to higher altitudes in response to climate change (Pounds *et al.*, 1999).

Future range shifts and contractions will occur as vast areas of bird habitat are lost or altered due to climate change, with bird population declines or extinctions inevitable. In North America, approximately 2.5°C of warming would reduce the world's most productive waterfowl habitat by two thirds (Sorenson *et al.*, 1998), cutting this zone's duck numbers by almost three quarters. In Europe, the boundaries of many birds' ranges would be required to shift 1,000 km or more under mid-level global warming of 2.5°C by 2100 (Huntley *et al.*, 2006).

Global warming of 3-4°C could eliminate 85 per cent of remaining wetlands worldwide, critical habitat for migratory birds (UNEP, 2005). Looking at threats to individual species, the Spanish imperial eagle and Marmora's warbler (both found only in Europe) will entirely lose their current range under future warming scenarios, putting them at high risk of extinction (Thomas *et al.*, 2004b; Birdlife 2004a). The outlook is bleak for the Scottish capercaillie, the highland habitat of which could shrink 99 per cent. This bird could disappear from the United Kingdom by 2050 (Berry *et al.*, 2001).

Rate of change too rapid: Human-induced climate change could cause historically unprecedented rates of change (Huntley *et al.*, 2006), with species forced to shift 10 times faster than during any climatic change seen at least since the last ice age (WWF, 2002). This will exceed the ability of many plants and animals to migrate or adapt, causing extinctions.

Barriers will prevent migration: As birds' climate space is altered with global warming, species may be unable to shift in tandem if their new potential habitat is rendered unsuitable by human development. Their current habitat may also be fragmented by human land use and disconnected from potential new, climatically suitable areas (Hannah *et al.*, 2005). Physical barriers such as mountains and large bodies of water present further obstacles to migration.

The prospect of such range shifts is of great concern to managers of conservation assets because many centres of species richness for birds are currently located in protected areas -- from which they will be forced by climatic changes into unprotected zones (Böhning-Gaese and Lemoine, 2004).

3.2.2 Indirect effects: Birds' natural communities disrupted

Also of highlighted concern is the threat range shifts caused by climate change will easily disrupt, or as some scientists describe it, "tear apart" ecological communities of birds and other interdependent plants and animals (Peterson *et al.*, 2002; Root *et al.*, 2003; Root and Hughes, 2005). This will occur because birds and the key species they interact with are unlikely to shift as intact communities. Birds will be brought into contact with different prey species, parasites, predators and competitors, as their habitats change or they are forced into areas less suited to them.

Seabirds are early responders to these shifts and illustrate the magnitude of threat. Warming ocean waters have caused key prey species underpinning the North Sea food web to shift (Lanchbery, 2005). In 2004 major declines in a small fish species known as sand eels caused complete and unprecedented breeding failure in seabirds on the North Sea coast of Britain, events linked to climate change (Lanchbery, 2005).

Thus shifts that re-organise natural communities are expected to produce further, still stronger, changes (Peterson *et al.*, 2002) as bird populations respond to new levels of prey, predation and disease.

4 The scale of climate change impacts

Climate change will have serious negative consequences for many bird populations (Berry *et al.*, 2001; Zöckler and Lysencko, 2000; DEFRA, 2005; Both *et al.*, 2006) and has already been linked to population declines and major reproductive declines. Looking to the future, the most serious of possible impacts - extinctions of entire bird species - are predicted.

4.1 Climate change affects bird populations

Studies are already linking climate change to declines in population and breeding success in bird populations around the globe. For some groups of birds, the effects are drastic.

Extreme weather events, a feature of global warming, appear to be increasing in frequency and magnitude (Parmesan, 2005). The radical 97 per cent breeding decline of California arid-land birds during a record 2002 drought potently illustrates the highly destructive and disproportionate effect of climate extremes on birds (Bolger *et al.*, 2005).

Island birds, as well as seabirds, are also highly vulnerable to climate change. Endangered Galápagos penguin populations have halved since the early 1970s because the adult penguins become emaciated and fail to reproduce during severe El Niño years (Boersma, 1998). Because climate models predict El Niños to become more frequent in the future (Timmerman *et al.*, 1999), climate change is expected to further reduce these small, restricted populations of Galápagos penguins and threaten them with extinction (Boersma, 1998).

4.2 Climate change will cause bird extinctions

Climate change puts many bird species at risk of extinction, even those currently considered safe (Birdlife, 2004a); and the stronger the climate change the stronger the risk. With a global mean surface temperature increase of 1-2°C above pre-industrial levels, many unique and threatened ecological systems will be at risk and numerous species will face extinction (Noble *et al.*, 2005; van Vliet and Leemans, 2006).

Risk is dependent on the species. The golden bowerbird, like many other bird species in the Wet Tropics of Australia's northeast, is particularly vulnerable. Its suitable habitat would decrease 63 per cent with less than 1°C of future warming (Hilbert *et al.*, 2004), illustrating why this zone's climate scenario has been called "an impending environmental catastrophe" by Williams *et al.* (2003).

Among particularly vulnerable groups -- migratory, Arctic, Antarctic, island, wetland, mountain and seabirds -- heightened impacts are expected. The threat of climate change to migratory birds is equal to the sum of all other human-caused threats combined (DEFRA, 2005) with 84 per cent of migratory bird species[2] facing some type of climate change threat. For example, the Arctic-breeding red-breasted goose, already globally vulnerable, is expected to lose 99 per cent of its tundra breeding habitat due to climate change (Zöckler and Lysenko, 2000). Birds that are habitat specialists are at higher risk than generalists (Huntley *et al.*, 2006; RSPB/WWF 2003). Birds breeding in arid environments (Bolger *et al.*, 2005) and those with low population numbers, poor dispersal ability, already poor conservation status, and restricted or patchy habitats or limited climatic ranges are also at elevated risk from climate change (Reid *et al.*, 2005; Huntley et al, 2006).

The overall extinction risk of climate change to birds is still being quantified. However, first-cut estimates present the possibility of the extinction of more than a third of European bird species under a maximum (>2.0°C) climate change scenario, if birds cannot shift to new climatically suitable ranges (Thomas *et al.*, 2004). Indeed their capacity to shift is subject to considerable uncertainty given Europe's heavily modified landscape (Huntley *et al.*, 2006). One candidate for extinction is the Scottish crossbill, expected to lose 100 per cent of its current habitat (Thomas *et al.*, 2004b).

In the Australian Wet Tropics bioregion, mid-range climate change is predicted to threaten almost three quarters of rainforest birds there with extinction in the next 100 years (Shoo *et al.*, 2005a). Table 1 provides estimates of bird extinction rates in four regions around the world, from Thomas *et al.* (2004).

However, many current projections of climate impacts, including those of the Intergovernmental Panel on Climate Change (IPCC), are likely to be underestimates (van Vliet and Leemans, 2006; Pounds and Puschendorf, 2004; Thomas *et al.*, 2004). Most research considers only the direct effects temperature or precipitation will have in shifting or contracting climatically-suitable ranges. Limiting the number of climate variables used potentially underestimates the risk of key climatic

2 Those birds listed with the Convention on the Conservation of Migratory Species (CMS).

Table 1: Bird extinction rates in four regions

Region	Predicted bird species extinctions		Warming Scenario[3]	Current number of bird species
	With Dispersal	No dispersal		
Europe	4-6%	13-38%	> 2 °C	524
South Africa	28-32%	33-40%	1.8 - 2.0 °C	951
Australian Wet Tropics	49-72%	N/A	> 2 °C	740 (Australia-wide)
Mexico	3-4%	5-8%	1.8 - 2.0 °C	1060

(Data from Thomas *et al.*, 2004)

changes (Pounds and Puschendorf, 2004). Very few studies capture indirect but important effects on ecological communities, such as the radical spatial shifts and timing mismatches discussed above. Furthermore, most analyses have not yet factored in the devastating impact of climate extremes, to which birds and entire ecosystems respond particularly rapidly and strongly (van Vliet and Leemans, 2006; Hannah *et al.*, 2005; Klein Tank, 2004).

Such factors explain why species are already responding more strongly than expected from the global warming that has occurred over the past century (Leemans and van Vliet, 2004). In fact, the expected combination of climate change and other human disturbances, such as habitat loss, has been termed an "extinction spasm" due to its potential to disrupt communities and wipe out entire populations (Lovejoy and Hannah, 2005b).

5 Conclusion

Birds have served as reliable indicators of environmental change for centuries and now indicate that global warming has set in motion a powerful chain of effects in ecosystems worldwide. In this global status review there is growing evidence of climate change affecting birds' behaviour, ability to reproduce and even to survive.

Furthermore, the march toward a major bird extinction may be underway, with evidence of climate change linked to unprecedented breeding crashes, and declines of up to 90 per cent in some bird populations. Forecasts of bird extinction rates depend on the potential resilience of ecosystems, and vary from 5 per cent to over 70 per cent, based on current emission and warming trajectories. Unfortunately, our analysis indicates that more comprehensive consideration of risk factors is likely to upgrade such extinction estimates in future.

Given that climate change is expected to shift important, species-rich bird communities out of protected areas, continued research is crucial. Thus if conservation efforts are to meet the climate threat, a fundamental change in approach to bird conservation will be needed if bird species diversity is to be maintained.

The most fundamental variable in the future impacts on birds will be the extent of global warming, which is dependant on to what extent and how quickly emissions of greenhouse gases are reduced. Interventions that reduce future greenhouse gas concentrations and therefore warming levels could also lessen the extinction rates of bird species and other groups.

3 Refers to global temperature increases.

Bird Species and Climate Change

1.0 Introduction

"There are many examples of the effects of climate change on birds from around the world, which taken together, provide compelling evidence that climate change is already affecting birds in diverse ways. It is these proximate responses that drive the ultimate impacts of climate change on species - the significant changes to ranges that will be catastrophic for many species"

State of the World's Birds, Birdlife, 2004a

1.1 Aims and methods

This review aims to answer the question: what is the threat of climate change to birds? Knowledge in this field is advancing rapidly. More is known about birds than any other class of animals (Berthold *et al.*, 2004), and of all groups of plants and animals the scientific analysis of likely future impacts from climate change is most developed for birds (DEFRA, 2005). Furthermore, birds provide some of the clearest examples of impacts already underway (Birdlife, 2004a).

However, to date relatively few studies -- with some notable exceptions -- seek to provide an overarching view of how birds as a group are responding to climate change at the regional, continental or global level. At the same time, hundreds of localised studies on individual bird species or groups of species provide insight into how the threat is playing out in a multitude of ecosystems. This research is most detailed in Europe and North America, with far fewer studies from Asia and the southern hemisphere (Moller *et al.*, 2004).

This review seeks to provide a global overview of current effects of climate change on birds as well as a picture of future impacts. It provides a scientific assessment of current research data, achieved by surveying hundreds of research articles and reports on the topic.

Declining ivory gull at risk in warming Arctic

1.2 How the climate is changing

It is now 10 years since the United Nations' leading scientific authority on global warming, the Intergovernmental Panel on Climate Change (IPCC), asserted that there was a "discernible human influence on global climate" (IPCC, 1996). Since then, evidence of climatic shifts has become increasingly apparent. With 0.8°C of average global warming having already occurred over the past century (Hansen *et al.*, 2005), the world is in the early stages of anthropogenic (human-caused) climate change. The effects on ecosystems are already clearly visible, from the poles to the tropics, and from the level of species up to entire communities. Models forecast further warming in the order of 1.4 to 5.8°C by 2100 (IPCC, 2002; this projection is expected to be revised to 2.0 to 4.5°C, under a scenario of a doubling of CO_2, in the United Nation's [UN] upcoming Fourth Assessment Report [Giles, 2006]), at a rate of warming unprecedented in at least the last ten thousand years (IPCC 2002).

1.3 How climate change is already affecting biodiversity

"Global warming represents perhaps the most pervasive of the various threats to the planet's biodiversity, given its potential to affect even areas far from human habitation."
Malcolm *et al.*, 2006

Biodiversity, or biological diversity, refers to the planet's sum total of species, ecosystems and genetic diversity. There is a broad scientific consensus that climate change has already had a "widespread and coherent impact" on biodiversity (IPCC, 2001b), and that it is an increasingly significant driver of biodiversity loss (UNEP, 2006). Significant impacts already underway include changes in the distribution of species, population sizes, timing of migration or reproduction, and increase in outbreaks of pests and disease (Reid *et al.*, 2005).

According to the UNEP (United Nation Environment Program) Millennium Ecosystem Assessment, "The balance of scientific evidence suggests that there will be a significant net harmful impact on ecosystem services worldwide if global mean surface temperature increases more than 2°C above pre-industrial levels ..." (Reid *et al.*, 2005).

Van Vliet and Leemans (2006) predict "devastating impacts to species and ecosystems" even "with a moderate climate change (an increase of 1 to 2°C)" above pre-industrial levels. Whether this level of warming is reached depends on the level at which greenhouse gas concentrations can be stabilised.

1.3.1 Rate of warming a crucial factor

The rate of warming is also a threat (IPCC, 2001c). With warming of 1°C per century by 2100 (0.1°C per decade) van Vliet and Leemans (2006) found that "only 50% of the affected ecosystems were able to adapt. With increasing rates of warming, the adaptation capacity rapidly declines." The UNEP Millennium Ecosystem Assessment finds that a rate in excess of 0.2°C per decade would have a "net harmful impact on ecosystem services worldwide" (Reid *et al.*, 2005). Given the current high rate of climate change (greater than 0.2°C per decade) we can soon expect an accelerating decline in biodiversity and ecosystem services (Leemans and Eickhout, 2004).

In the future, climate change is expected to affect all aspects of biodiversity (IPCC, 2002; Reid *et al.*, 2005). This threat has compelled some experts, including bird conservationists, to state that climate change is emerging as the greatest long-term risk to biodiversity in many, or even most, of the world's regions in coming decades (Malcolm *et al.*, 2006; Thomas *et al.*, 2004). According to Thomas E. Lovejoy, editor of two research books on biodiversity and climate change, "It is now clear that climate change is the major new threat that will confront biodiversity this century, and that if greenhouse gas emissions run unchecked until 2050 or beyond, the long-term consequences for biodiversity will be disastrous" (Lovejoy and Hannah, 2005b).

1.4 The current conservation status of birds

There are 9,787 known living species of birds of which 21 per cent (or 2,055 bird species) are currently extinction-prone due to a wide variety of threats (Sekercioglu, 2004), from habitat destruction to poaching. The conservation status of birds has continued to deteriorate since the first complete global assessment of this group was made in 1988 (IUCN, 2004). Since 1994, the number of bird species at risk has increased by 400 and trends suggest 600 to 900 more bird species could soon be deemed at risk (IPCC, 2001b). Habitat destruction and fragmentation is the most pervasive threat, impacting 86 per cent of threatened birds. However, climate change is emerging as a very serious threat to biodiversity as well, with mid-range climate change scenarios expected to produce greater extinction rates in animal and plant species than habitat loss (Thomas *et al.*, 2004).

2 The ways in which climate change acts upon birds

"Climate change affects ecosystems, habitats and species with increasing velocity and continuity."
Bairlein & Hüppop, 2004

This section provides a brief overview of how climate change can affect birds. The effects touched upon here will be further elaborated on, and concrete examples provided, in subsequent sections.

Distributions of birds, like most plants and animals, are limited by climatic factors including temperature, precipitation, and wind. Indeed climate is one of the most important factors in determining birds' ranges and abundance (Jones *et al.*, 2003). At high latitudes, temperature most influences the number of species found (species richness), while at low latitude, high temperature regions, water-related climate variables are more important (Böhning-Gaese and Lemoine, 2004).

"Climate" refers to the aggregate of weather events over the long term. The effects of weather on birds are well known (Crick, 2004), being both diverse and important. Consequently birds are very sensitive to changes

Figure 1

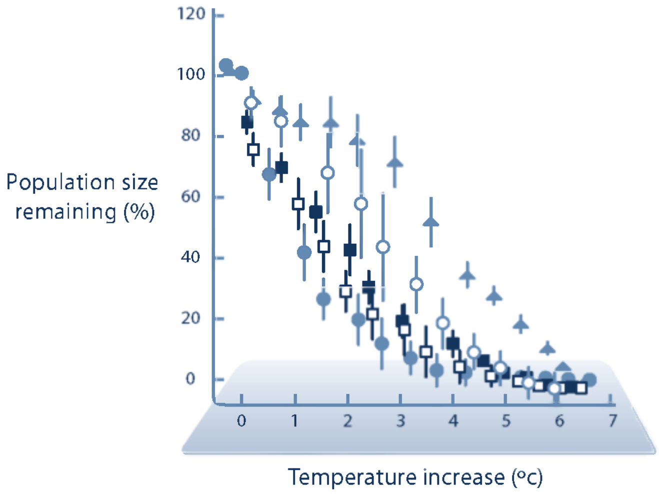


Figure 1: Population decline of 55 Australian rainforest bird species with climatic warming for the year 2100, if no migration is possible (Shoo *et al.*, 2005a). These Wet Tropics bioregion species are found in habitats of varying altitudes: filled triangles = species inhabiting 0-299 m; open circles = 300-599 m; filled squares = 600-899 m; open squares 900-1199 m; filled circles = 1200-1499 m. (See section 6 for further information.)

in climate (Berthold *et al.*, 2004). Compelling evidence shows that birds are responding to climate change, which makes them "pioneer indicators" for changes related to global warming (Berthold *et al.*, 2004) -- the quintessential "canaries in the coal mine".

2.1 Changes in temperature

Temperature affects birds both directly and indirectly. Birds are warm-blooded (endothermic) animals and must maintain constant body temperature. The response of birds to climate change will vary from species to species, depending on how strongly their metabolism reacts to new temperature levels (Root and Hughes, 2005).

Climate change will affect temperatures in regions around the globe differently. Higher latitudes (i.e. regions closer to the poles) are generally undergoing more intense changes in temperature, with the Arctic warming almost two times the global average rate over the past few decades (ACIA, 2004), thus habitat loss is expected to be most marked toward the poles (WWF, 2000) as species respond to this change.

Where local and regional climates warm due to climate change, bird species are expected to shift their distributions either pole-ward or upward in elevation (in mountainous zones) to maintain their optimum temperatures. Because some species are adversely affected by temperature increases as small as 1°C (Hilbert *et al.*, 2004; Shoo *et al.*, 2005a), they face an uncertain future if they cannot shift their distribution to track their optimum climate envelope.

2.2 Changes in precipitation

Precipitation and moisture are critically important climate variables to birds, and changes are expected to affect birds both directly and indirectly. Some species, including inland water birds such as ducks, are highly dependent on precipitation to sustain their wetland habitats. Consequently, precipitation reductions have major implications for these species.

And although warming is likely to be the more critical climatic variable for bird species at higher latitudes, at the tropics precipitation timing and intensity may be more critical (Root and Hughes, 2005). Periods of low or zero rainfall tend to be linked to reduced bird populations because these dry spells reduce bird food sources, such as insects and fruit (Williams *et al.*, 2003).

Precipitation, along with temperature, is also especially likely to influence the behaviour of migratory birds. It is expected to affect their decision to depart for migration indirectly by acting on food availability and birds' consequent ability to build up energy reserves. Drought in critical stopover areas for migratory birds affects their ability to refuel on water and prey before crossing barriers such as deserts (Bairlein and Hüppop, 2004).

Changes in snowfall will also affect birds in mountain habitats if these species depend on areas of freshly melted snow to keep the ground wet and rich in insect life (Inouye *et al.*, 2000).

2.3 Greater Climatic Extremes

Scientists believe that global warming is contributing to more extreme weather events, with heat waves, droughts (IPCC, 2001c) and tropical storm intensity (Webster *et al.*, 2005) expected to escalate in the future. More frequent occurrence of these extremes, including temperature and precipitation extremes, will affect the survival of birds and other wildlife. Upper and lower precipitation and temperature limits play an especially important role in determining the distributions of birds and other wildlife (Parmesan, 2005).

Extreme weather can affect survival, especially of young birds but also adults (Crick, 2004; Stokke *et al.*, 2005; RSPB, 2004b), particularly in the highly variable Arctic climate where a summer storm can eliminate an entire generation of young birds (ACIA, 2004). European birds and their young are also vulnerable to extreme events and more negative impacts can be expected in the future (Stokke *et al.*, 2005).

Because some migratory birds are pushed to their limits of endurance during migration, increased frequency of storms reduces some species' ability to reach breeding grounds (DEFRA, 2005).

Increased extreme weather events such as storms will also harm birds' habitats by eroding mudflats of estuaries that are important feeding sites for birds (DEFRA, 2005). Along with sea level rise, storms will inundate low-lying islands and seabird nesting colonies on them will be lost (UNEP, 2005).

Climate change is also expected to make weather more variable (IPCC 2002). This is significant because birds expend more energy after sudden temperature changes and if temperatures are more varied. If energy is not abundant to compensate for such additional expenditure, birds may lay smaller eggs, for example (Pendlebury *et al.*, 2004) .

We can also expect bird species to be affected by more intense and prolonged El Niño events, another feature of global warming (DEFRA, 2005). Researchers have linked El Niño years with death of adult birds and reduced production of young (Mazerolle *et al.*, 2005).

2.4 Indirect effects of climate change

"Climate change will often act in combination with major threats such as habitat loss and alien invasive species, making their impacts considerably worse…"

Birdlife, 2004a

Habitat changes: With a doubling of CO_2, climate change could eventually destroy 35 per cent of the world's existing terrestrial habitats (WWF, 2000). Birds' habitats will be altered through changes in sea level, fire regimes, vegetation and land use (Böhning-Gaese and Lemoine, 2004; IPCC, 2001b).

Warming will reduce tundra breeding grounds for Arctic terns and other migratory birds

Over the last 100 years, the global sea level has risen by about 10-25 cm, depending on location. As noted above, rising sea levels can combine with increased wave activity during storms to inundate, erode or alter important bird habitat.

Sea level rise is expected to inundate lowland coastal bird habitats around the world, including marshes. One important effect will be "coastal squeeze". As rising sea levels inundate existing estuaries and deltas, hard sea defences and agricultural or urban land will effectively form barriers against the natural retreat of these habitats up the shore (i.e., further inland; UNEP, 2005). This combination of rising sea level and coastal squeeze could permanently inundate mudflats, severely impacting wildfowl and wader species (DEFRA, 2005). As noted above, rising sea levels will combine with tidal surges to threaten the nests and young of birds on low-lying islands or near the shore.

By increasing the length and intensity of summer drought in many parts of the world, climate change has increased the susceptibility of ecosystems to fires. Fire, and fire frequency has increased (IPCC 2001b), destroying forest bird habitat. Climate change is also expected to cause major shifts in vegetation, further reducing bird habitat. Climate change could also prompt shifts in land use by humans, such as agriculture change, which will also impact on birds.

Shifts in communities: Because climate change is also expected to shift the distribution of plant and animal species pole-ward or upwards in altitude with warming, the overall indication is that

Figure 2: Current and projected vegetation shifts in the Arctic with climate change.

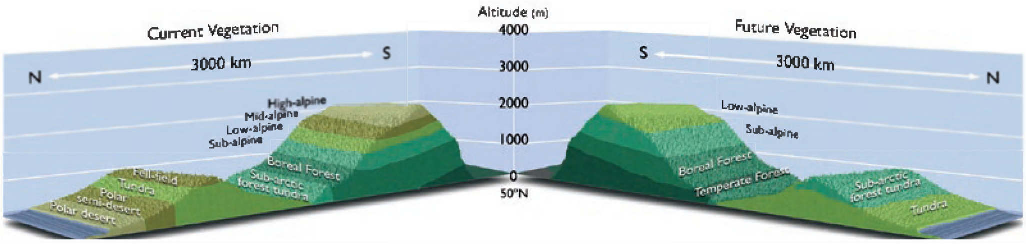


Figure 2: Current and projected vegetation shifts in the Arctic with climate change. Note that vegetation types move pole-ward and upward in elevation (ACIA, 2004).

many bird species will have to compete with, or be displaced by, invading species. Bird food species may also be affected by changes in temperature (Both *et al.*, 2006), wind patterns or altered ocean currents (Peterson, 2005). Climate change can also affect the incidence of disease in birds (Epstein, 2001).

This potential for climate change to “re-shuffle” ecological communities is discussed in greater detail below.

3 How climate change pushes birds out of ecological synchrony

This section examines how climate change is forcing a shift in the key life cycle events of birds, such as nesting and migration. It will show how birds’ behaviour, in many cases, is shifting in response to climate change at a different rate from that of key species (e.g. prey and parasites) and natural events upon which birds depend to complete their life cycles. It demonstrates how these differential shifts threaten birds’ breeding success and survival.

3.1 Birds’ seasonal responses are shifting: Phenology

“It’s when the canary keels over that you know you’re in trouble–and these changes in phenology are the canary.”

Ecologist Alastair Fitter, York University, UK (from Jensen, 2004)

Birds’ life cycles and behaviour are closely tied to the changing seasons. Seasonal variables including temperature and precipitation also affect the availability of flowers, seeds, insects and other food sources for birds (NWF/ABC, 2002). The study of the timing of recurring natural phenomena such as migration, nest building and egg laying, especially in relation to climate, is known as phenology.

The effects of climate change on these important behavioural or biological events is already well documented, with robust studies showing a strong response to climate change in birds. The changes are of concern because they can force a given bird species’ lifecycle out of synchrony with the ecosystems and communities of which it is a part, an effect discussed further below.

Figure 3

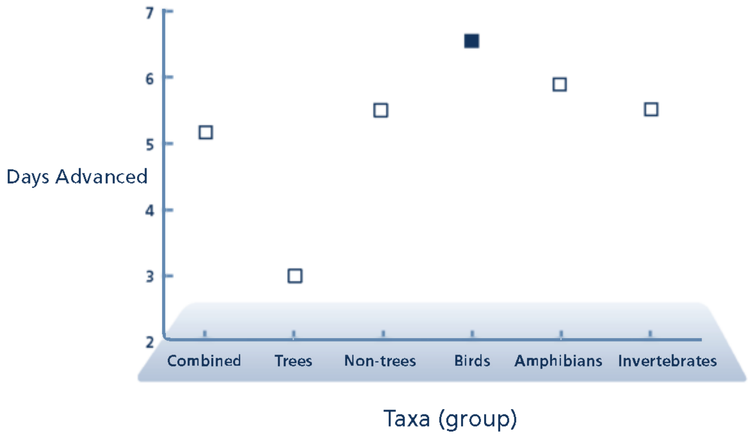


Figure 3: Analysis of over sixty studies reveals that birds around the world have advanced the timing of spring phenological phenomenon, such as migration and egg-laying, at a rate of 6.6 days per decade on average. "Non-trees" refers to plants other than trees (Root and Hughes, 2005).

We know with certainty that birds are already responding to climate change. One analysis of more than sixty phenology studies worldwide (Root *et al.*, 2003) found birds had advanced timing for spring phenological phenomenon at an average rate of 6.6 days per decade. Furthermore, these shifts were in the direction consistent with climate change (see Figure 3; Root and Hughes, 2005).

Large numbers of studies in Europe have also documented shifts in migration, timing of mating, nest-building, egg-laying and clutch size in response to climate change. The small cross section of research presented here reveals the types and extent of change.

3.1.1 Egg laying dates:

Strong evidence documents earlier egg-laying by birds in response to climate change. Approximately 60 per cent of studies on egg-laying show long-term advances in laying date consistent with patterns of global warming (Dunn, 2004).

In Europe:

- A 25-year study of UK birds found that 20 out of the 65 species studied were laying eggs 8.8 days earlier on average (Crick *et al.*, 1997). Another study found a strong (statistically significant) correlation between laying date and climate change (Crick and Sparks, 1999).

- Analysis of 23 long-term studies of European flycatchers using data from 40,000 nests shows laying dates advanced significantly in nine out of 25 populations; furthermore, the more the temperature increased at the site, the more the laying date advanced (Both *et al.*, 2004). Laying dates advanced significantly over the years in nine out of 25 populations. Furthermore, "20 out of 25 populations show a significant effect of local spring temperature on laying date," that is, the more temperatures increased at a site, the more the laying date advanced.

In North America:

- New research using 50 years of data demonstrated that four ecologically diverse species are laying eggs earlier in conjunction with warming local climates (Torti *et al.*, 2005).

- The North American common murre (also known as the common guillemot) has advanced its breeding date 24 days per decade (Root *et al.*, 2003).
- The mean laying date for Mexican jays' first clutch of eggs advanced by 10.1 days over a 1971-1998 study period. Noting that initiation of laying is sensitive to warmer springtime minimum temperatures, Brown *et al.* (1999) reported that "changes were associated with significant trends toward increased monthly minimum temperatures on the study area, traits that are associated with the onset of breeding in this population."

3.1.2 Migration timing

Spring migration of birds is generally considered more important than autumn migration because it determines their arrival timing at breeding grounds, which is in turn crucial for mating and territory choice. The number of successful spring migrants also directly affects breeding population size (DEFRA, 2005).

3.1.2.1 Spring migration advances

In general, research indicates birds are migrating earlier in spring in conjunction with warming climates. However, long-distance migrants seem to be lagging behind short-distance migrants in terms of their response, an effect discussed further in this section.

The evidence for earlier spring migration is powerful, as the examples below indicate. The linkage between earlier arrival dates and climate change is strengthened by data showing arrival dates are unchanged where no (significant) local temperature change has been observed, and arrival dates are later where local temperatures have actually become cooler (DEFRA, 2005).

In Europe:

- In the UK, where decades of extensive records exist, three studies have found that between 26 per cent and 72 per cent of recorded migrant bird species have earlier spring arrival, with arrival date advances of up to two weeks over the past two to three decades (DEFRA, 2005).
- Analysis of more than two dozen studies throughout Eurasia shows first arrival date for migrants in spring advanced an average of 0.373 days/year (3.73 days per decade) towards the end of the 20th century in conjunction with climate warming. This includes birds in Norway, Russia, Finland, Estonia, Denmark, Lithuania, France, Poland, Germany and Great Britain (Lehikoinen *et al.*, 2004).

In North America:

- A 63-year data set on first spring sightings for 96 species of migrant birds in Canada revealed that, as mean monthly spring temperatures increased (by 0.6 - 3.8°C), 27 species altered their arrival dates significantly, most arriving earlier. Only two species arrived later, "evidence that climate warming has influenced spring migration arrival dates of several species in Manitoba" (Murphy-Klassen and Heather, 2005).

In Australia:

- Arrival dates for 24 species and departure dates for 12 species of birds were analysed using data spanning the past 40 years. On average, birds are arriving 3.5 days earlier per decade since 1960, with half the species showing significantly earlier arrival. These results, reported by Beaumont *et al.* (2006), "add further evidence that the modest warming experienced over the past few decades has already had significant biological impacts on a global scale."

In Antarctica:

- East Antarctic seabirds, including Adélie penguins and six species of petrel, are arriving at their colonies an average of 9.1 days later and laying eggs 2.1 days later than in the early 1950s. Some birds are arriving as much as 30 days later than in the 1950s. The findings have been linked to global climate change which has decreased sea ice extent in this region overall, but caused the sea-ice season to increase by more than 40 days due to localised cooling since the 1970s. These changes are associated with declines in krill, a key prey species. The birds' delayed arrival and laying dates may reflect the longer feeding time to build up the energy reserves required to breed (Barbraud and Weimerskirch, 2006).

3.1.2.2 Autumn departure shifts

Birds' autumn departure dates also appear to be changing, however this effect is more difficult to monitor (Crick, 2004). This response to climate change also appears more variable with some species advancing and others postponing their autumn migration. These differences appear to reflect the relative importance of summer and winter seasons in completing birds' life cycles (Lehikoinen *et al.*, 2004).

In Europe:

- Birds that winter south of the Sahara have advanced autumn migration an average of 2.5 days in the last 40 years, possibly so they can cross the Sahel before the seasonal dry period. By contrast, migrants wintering north of the Sahara have delayed autumn passage by 3.4 days on average over the same period (Jenni and Kery, 2003).

In North America:

- Of 13 North American passerine bird species, six were found to delay their migration dates in conjunction with global warming (Mills, 2005).

3.1.2.3 Failure to migrate

In Europe it appears that climate change is causing individuals of some bird species (which normally migrate) to fail to migrate at all.

This includes greenfinches, which have seen a six-fold increase in their winter populations in Finland in the last 40 years, as fewer individuals migrate to Northern Germany (Lehikoinen *et al.*, 2004).

3.2 Climate change causes mismatch between behaviour and environment

"Global warming may cause migration and nesting to get out of step with food supplies. As a result, the 'early birds' may not get the worm"

NWF/ABC, 2002

As demonstrated above, many bird species' migratory and reproductive behaviour is shifting with climate change. But there is concern some bird species may not be able to alter their behaviour sufficiently to match shifts in the availability of important food sources such as insects, flowers and berries.

A timing mismatch between predator and prey could cause major species declines if birds are unable to complete their life cycles (Both *et al.*, 2006). For example, migrant birds may be unable to breed successfully because their arrival time no longer coincides with peak food availability. Biologists refer to this as "phenological mismatch". It may occur because birds, and the species on which they depend, are driven by different cues. For example, one animal's behaviour may be cued by day length, the other by temperature (Pew, 2004; Visser *et al.,* 2004).

Research shows the extent of the mismatch already underway today. Advancement in the laying date of British migratory birds (typically two days per 1°C) appears to be lagging behind advances in vegetation and invertebrate phenology (six days per 1°C; DEFRA, 2005). Such animals could be caught in a race against time as they evolve to adjust to shifts in the seasonal availability of food sources triggered by climate change (Pennisi, 2001; Thomas *et al.*, 2001). Some bird populations are already in major decline due to climate change-induced mismatch (Both *et al.*, 2006) and there are indications this mismatch could also hasten the decline of species that are already endangered (Scheigg *et al.*, 2002).

Given the enormous complexity of food webs, the balance of evidence indicates that more such problems are very likely to occur. However, the current lack of data on this subject makes it difficult to quantify the level of risk to birds (Leemans and van Vliet, 2004).

In Europe:

- In Spain, leaves on trees are unfolding 16 days earlier and plants flowering six days earlier than in 1952; fruiting is nine days earlier than 1974. Yet spring migratory birds are arriving 15 days later than in 1952; researchers speculate this effect is due to climatic changes in their wintering area (Penuelas *et al.*, 2002).
- In France, blue tits in Montpellier are exerting themselves at almost double the normal metabolic rate as they forage to feed their young. Climatic warming has meant the birds are failing to breed when and where their food is in peak abundance, forcing them to exert extra energy to forage. According to Pennisi (2001), "These parents' overall survival suffered because they had to work harder to feed their young."

In North America:

- Research on endangered red-cockaded woodpeckers in North Carolina over two decades shows that while normal birds were laying eggs earlier in response to a warming climate, pairs that included an inbred partner were not (Scheigg *et al.*, 2002). Since endangered species are often reduced to small, isolated populations that become inbred, "climate change poses a previously unknown threat that may hasten the decline of endangered species," according to Karin Schiegg.[4]

3.2.1 The vulnerability of long-distance migrants

"Long distance migrants have an extra handicap to adjust their breeding date to climate change, because on the wintering grounds it is often impossible to predict changes in the onset of optimal conditions in the breeding grounds."

Visser *et al.*, 2004

Long-distance migratory birds do not appear to be responding to climate change (by shifting their migration timing) as rapidly as short-distance migrants, according to several pieces of research (Crick, 2004; Mills, 2005; Tryjanowski, 2002). The different responses are believed to stem from different underlying processes that determine migration timing of these two bird groups. It suggests that long-distance migrants are more likely to suffer from of climate change-induced mismatch with their environment (Coppack and Both, 2002; Visser *et al.*, 2004). As a result, they may be more likely to suffer as a result of climate change.

For species that do not migrate, local weather and vegetation act as reliable cues to start breeding. However, migrating birds, and especially long-distance migrants, are removed from the food sources at the other parts of their migratory path. Instead they respond to "internal clocks", environmental stimuli unrelated to temperature (Coppack and Both, 2002; Barlein and Huppop, 2004) or weather circumstances along the migration route (Gwinner, 1996). Climate change may advance events such as insect emergence in the migrants' breeding areas; but if a given species' spring migration does not advance in keeping with their prey, they are at a greater risk of being out of synchrony (Both and Visser, 2001; Visser *et al.*, 2004)

Some researchers argue that past selection pressure could have promoted a very stable timing of migration due to the severe reproductive consequences of arriving either too early or too late in spring breeding grounds (Coppack and Both, 2002). Genetically speaking, this means that long-distance migrants could lack the ability to change the timing of migration (Coppack and Both, 2002; Pullido and Widmar, 2005). According to Pullido & Widmar (2005), "If this were true, the adaptability of long-distance migratory birds would be limited, which would explain the vulnerability of this group of birds to environmental changes."

4 Quote from NWF (undated).

This is of special concern given an overall trend of strong decline for long-distance migrants in North America and across Europe, with long-distance migrants doing significantly worse than short-distance migrants or resident birds (Sanderson *et al.*, 2006; Both *et al.*, 2006; Birdlife, 2004b). Climate change-induced mismatch is probably a widespread phenomenon and strong evidence already ties it to major population declines in some long-distance migrant bird populations (see case study 1; Both *et al.*, 2006). There is concern it could cause further collapse in breeding populations of such birds in the future (Sanz *et al.*, 2003).

Other climate change related risks faced by long-distance migrants and other migratory birds are detailed in section 6.

African -- not European -- conditions more strongly influence the hoopoe's spring arrival in Europe

In Europe:

- Fifty years of data revealed that for six trans-Saharan migrant bird species, conditions in the birds' African wintering quarters had a stronger influence on first spring arrival dates than their European (western Mediterranean) breeding grounds. Temperature and especially precipitation affected departure decisions indirectly by acting on food availability and the build up of energy reserves required for the birds to migrate, illustrating the complex effects of climate change on the birds' life cycles (Gordo *et al.*, 2005).
- Changes in timing of vegetation growth could lead to a mismatch between migration time and optimum vegetation conditions at stopover sites for long-distance migratory geese, and other plant-eating migrant birds that depend on high-quality forage plants at a small number of staging sites (Bairlein and Hüppop, 2004).
- New research reveals 54 per cent of 121 long-distance migrants studied have shown sustained, often severe, decline or even become extinct in many parts of Europe since 1970, with climate change implicated as a major contributing factor (Sanderson *et al.*, 2006).

In North America:

- Short-distance migrants in the United States arrived an average of 13 days earlier in their summer grounds in New York and Massachusetts during the period 1951-1993 than in the first half of the century; yet long-distance migrants arrived just four days earlier (Butler, 2003).
- Wood warblers showed no significant tendency to migrate earlier from their neotropical wintering grounds, despite earlier springs in their northern US breeding range. According to Strode (2003), "These results suggest that climate change may force many species of long-distance migratory songbirds to become uncoupled in the spring from their food resources that are driven by temperature."

CASE STUDY 1: EUROPE

Pied flycatchers fail to keep up with climate change

The pied flycatcher is a small, insect-eating, long-distance migratory bird with relatively fixed migration timing. It winters in West Africa and migrates thousands of kilometres to breed in the spring in the UK, northwest Europe and Poland and Russia. Though not currently threatened, recent evidence reveals some pied flycatcher populations are declining in the face of existing rates of climatic change in their European breeding grounds.

The birds appear to be nesting more quickly after their arrival in spring, which helps compensate for earlier emergence of their caterpillar prey, which also grow and pupate faster in response to warming (Both and Visser, 2001; Both *et al.*, 2006). However, the birds do not appear to be shifting their spring arrival time. If caterpillar populations peak too early, pied flycatchers are simply unable to nest, lay eggs and produce hatchlings in time to capitalise on peak prey availability.

New research on nine pied flycatcher populations in the Netherlands from 1987 to 2003 reveals a 90 per cent decline in the birds' numbers in areas with the earliest food peaks, and much lesser declines of about 10 per cent in areas with the latest food peaks. Furthermore the populations that show the least adaptation to their changing environment -- those that advanced their laying date least - show the greatest population decline (Both *et al.*, 2006).

In a Mediterranean population of pied flycatchers this mismatch has also been linked to reduced nestling growth and a 15 per cent reduction in nestling survival (see figure 4). According to Sanz *et al.* (2003) "the breeding season has not shifted and it is the environment that has shifted away from the timing of the pied flycatcher breeding season". These authors state that if climate change and effects such as this are sustained in the long term, "it may imply a further collapse of breeding populations of long-distance migrants in the Mediterranean region".

Figure 4

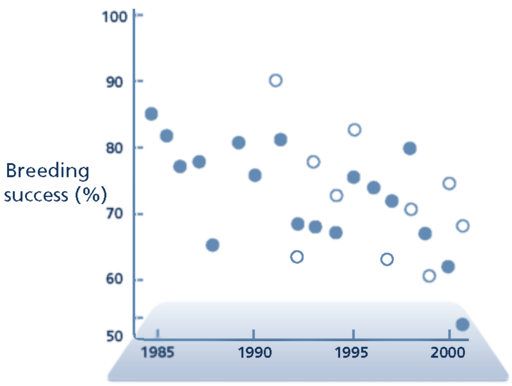


Figure 4: The breeding success of Mediterranean populations of pied flycatchers declined by approximately 15 per cent between 1984 and 2001. This long-distance migrant did not arrive in its breeding grounds early enough to breed and match its nestling demand with peak food supply. Insects now emerge and peak earlier in keeping with global warming (Sanz *et al.*, 2003).

Solid dots represent the La Hiruela study area, hollow dots the Valsain study area.

4 How climate change shifts ranges & disrupts communities

"Rapid movement of climatic zones is going to be another stress on wildlife ... In effect we are pushing them off the planet."

James Hansen, NASA Goddard Institute for Space Studies (from Hansen, 2006)

This section discusses how climate change causes spatial shifts in populations. This can directly affect birds by causing major population reductions, or in future, could result in their complete collapse. We will further discuss indirect effects of such shifts that arise because different species will shift at different rates as they respond to climate change, forcing birds into new and "reshuffled" habitats and communities. This effect brings additional, possibly greater, threats of its own.

4.1 Climatically forced shifts in distribution

"How species will find and move to suitable new locations, and what other elements of their habitat they will find there, are difficult questions that scientists and governments are still exploring."

RSPB, 2004a

The strong relationship between bird distribution and climate (Root, 1988) means that when climatic boundaries change, bird distributions are expected to shift too (DEFRA, 2005). In the northern hemisphere the northern boundaries of bird distributions are limited by cold temperatures, while the southern boundaries tend to be limited by heat or water scarcity in arid regions, and competition between species, predation and parasitism in humid zones (Böhning-Gaese and Lemoine, 2004).

If local and regional climates follow global averages by warming, bird species could be expected to shift either upward in elevation, or pole-ward, (although exceptions exist) to track their optimum temperatures. In addition to temperature, moisture, precipitation and invasion by competing species are other direct and indirect climate-mediated factors that can be expected to affect distributions of bird populations(DEFRA, 2005).

4.1.1 Human barriers to migration

Of course distributional shifts of species have occurred across time in conjunction with climate change. However, a threat today, in addition to the rate of climate change (see section 1), is that habitats are increasingly fragmented by human development. Consequently climatically-induced migrations will be checked by cities, highways, farms and other human barriers (Hannah *et al.*, 2005; Parmesan, 2005), in addition to natural geological barriers, such as mountain ranges or large bodies of water.

Habitat fragmentation reduces the ability of birds to disperse into new areas and causes lags in distributional shifts (RSPB/WWF, 2003; NWF/ABC, 2002). According to the IPCC (2001b), fragmentation can also facilitate the introduction of invasive species into an area "leading to potential population declines through predation, competition, or transmission of disease." Fragmentation will be a key factor affecting species' response to climate change (RSPB/WWF, 2003).

4.1.2 Changes undermine current conservation efforts

"Conservationists are entering a new era of conservation, one in which last-ditch stands to save species where they currently exist may not be enough."

Hannah *et al.*, 2005

Distributional shifts are of great concern for international bird conservation efforts, which focus on areas with high numbers of endemic and threatened species. Many centres of species richness for birds are in protected areas. As climate change progresses, many populations of bird species' will be forced to shift out of protected areas and possibly into areas with human development or conflicting land use.

If birds cannot move and are forced to remain in areas that have become inhospitable, birds and other groups could see their range and population size decrease until they eventually become extinct (IPCC, 2001b). As Walther (2002) puts it, "species with low adaptability and/or dispersal capability will be caught by the dilemma of climate-forced range change and low likelihood of finding distant habitats to colonize, ultimately resulting in increased extinction rates."

In North America:

- New findings conservatively project species losses of up to 20 per cent from US national parks (under a doubling of CO_2), potentially illustrating how the mandate of such parks to protect biodiversity would be compromised with climate change (Burns *et al.*, 2006).

A stark summation is provided by the Pew Centre: "Species that are not adapted to urban and agricultural environments are likely to be confined to smaller total geographic areas as climate causes them to contract from their southern[5] and lower boundaries. Already rare or endangered species, or those living only on high mountain tops, are likely to have the highest risk of extinction" (Pew, 2004).

This is of special concern to conservationists and agencies responsible for protecting birds' survival in future. According to the Royal Society for the Protection of Birds (RSPB, 2004c), "It seems that despite the work of conservation organisations like the RSPB, much of the hard work to preserve habitats and ensure the success and survival of our wildlife may be compromised by the effects

5 Explanatory note: refers to northern hemisphere species.

of climate change". Thus we find that climate change has the potential to seriously undermine existing conservation efforts (Böhning-Gaese and Lemoine, 2004), which may be inappropriately configured for a world in which the climate is changing.

Despite the seriousness of these effects, very few studies document climate change effects on birds' ranges and communities (Böhning-Gaese and Lemoine, 2004). A review of some available studies below summarises the findings.

4.1.3 Distributional shifts already underway

"There is some chance that climate change will induce major ecosystem shifts in some areas that would result in radical changes in species composition and unknown consequences."

ACIA, 2004

As expected, bird species are already shifting their distributions in response to climate change, with species in Antarctica, North America, Europe and Australia moving pole-ward (IPCC, 2001b), and tropical species moving up slope. Overall declines in the proportion of migratory species to resident species have also been observed with increasing winter temperature, as milder winters allow resident birds to out-compete migrants (Böhning-Gaese and Lemoine, 2004).

Strong evidence ties such responses by birds and other groups to climate change. An analysis of 434 range-shifting plant and animals species, including birds, from around the world revealed that 80 per cent of range shifts were in the direction expected from climate change, providing a high degree of confidence that natural communities are responding to climate change (Parmesan and Yohe, 2003).

In Europe:

- Climate change has forced changes in the wintering areas of the white-fronted goose, whooper swan and Berwick's swan. The birds' migration routes have shifted eastward and northward, and the birds are using new staging areas in the eastern Baltic (the Lithuanian coastal region) as a result. This has prompted urgent calls for new protected areas (Žalakevicius and Švažas, 2005).
- A large-scale survey shows UK bird species' ranges are shifting in response to a warming climate by extending northward, with northern margins of many species' distributions moving an average of 18.9 km further north over two decades. However, no consistent change was detected in the southern boundary of bird species' ranges. Climate change was "the most parsimonious explanation" for the observed changes (Thomas and Lennon, 1999).

In Central America:

- In Costa Rica, keel-billed toucans which previously bred only in lowlands and foothills are nesting alongside resplendent quetzals, birds which symbolise the Middle American "cloud forests" -- evergreen mountain forests shrouded in cloud or mist. This tendency of birds normally intolerant of cloud forest to colonise higher ground has been positively correlated with raising of the cloud bank and drier seasonal weather conditions, linked to climate change. Between 1979 and 1998, 15 such species both colonised the cloud forest habitat and established breeding populations there (Pounds *et al.*, 1999).

Moving on up: the keel-billed toucan

CASE STUDY 2: NORTH AMERICA

Seabird population declines 90 per cent with changing oceanic climate

The sooty shearwater is an abundant seabird thought to number 20 million individuals globally, and known to be highly sensitive to water temperature. It migrates from its southern hemisphere breeding grounds to spend the boreal (northern) summer on the west coasts of both Europe and North America to feed on fish and squid larvae.

An important sooty shearwater population in the California Current off North America's west coast declined 90 per cent through to the mid-90s, from a starting population of five million (Viet *et al.* 1996) . This occurred in conjunction with a rise in sea-surface temperatures consistent with global warming, and a reduction of available nutrients for plankton and prey.

It is still not known whether the population truly declined, or re-distributed to the North and Central Pacific where food may have been more abundant. However, according to Viet *et al.* (1997), "If the observed warming of the waters of the California Current System is an irreversible manifestation of a changing global climate, then the impact upon Sooty Shearwater populations seems likely to be profound."

In recent years a slow and partial recovery has been observed in this California Current population (Sydeman, 2005) consistent with this species' low reproductive rate. This could also reflect re-distribution back into the area; however, the balance of evidence suggests a slow recovery from a population decline.

Figure 5

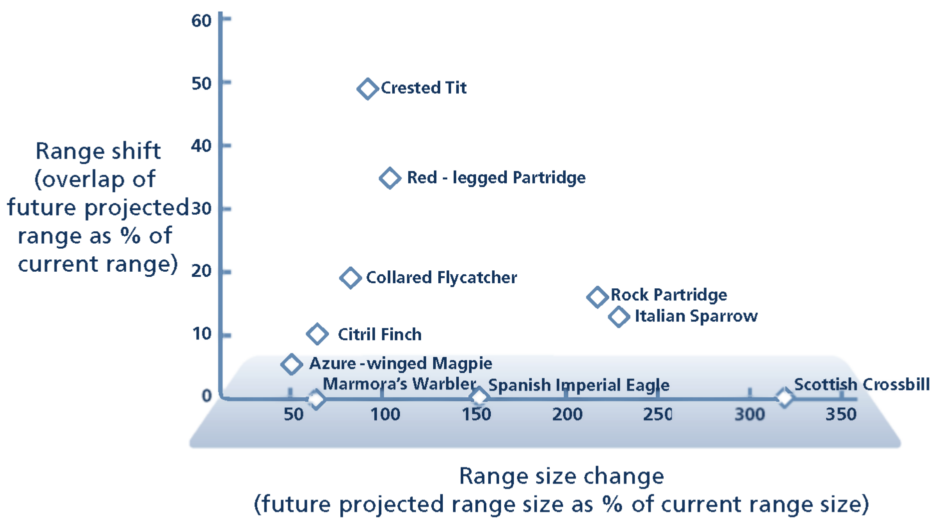


Figure 5: Overlap of current ranges of 10 endemic European birds and future ranges at the end of the 21st century, according to a climate model.[6] The Y axis shows range overlap, the X axis future range extent. The citril finch's range, for example, will shrink by half, and its future climate space will overlap with its current range by only 10 per cent. Of serious concern are those species with zero projected overlap between present and future range (Birdlife, 2004a).

4.1.4 Forecasts of distribution changes

> "The most frightening result of all approaches to model range changes are the large movements of ranges expected to occur within the next 50-100 years."
>
> Böhning -Gaese and Lemoine, 2004

Climate change is expected to cause significant range contractions in populations of many bird species, as the area of climatically suitable habitat available to them shrinks or almost disappears. Some bird species' distributions may expand or remain unaffected by climate change (DEFRA, 2005) but, importantly, indications are that range contractions will be more frequent than range expansions (Huntley et al., 2006; Böhning-Gaese and Lemoine, 2004; Erasmus et al., 2003). Research on European birds indicates substantial shifts of 1000km or more for many bird species under mid-level global warming of 2.5°C by 2100 (Huntley et al., 2006).

Even if a species' theoretical climate space does not shrink, that species will be threatened if its "climate space" shifts to an area where it is unable to follow, or that is fundamentally unsuitable for other reasons, as discussed above.

Species with ranges that both contract and shift are expected to be most threatened by climate change and in some cases this threat could be severe enough to cause extinction (Birdlife, 2004a).

In Europe:

- Mapping the future climatically suitable area for 10 land birds endemic to Europe

6 The model is from Gordon *et al.*, 2000

Eighty four per cent of migratory bird species, including the Siberian crane, face some type of climate change threat

revealed that for six species, suitable climate space will decrease. However, even when it does not decrease there is little overlap between future and current modelled ranges. For eight species, 20 per cent overlap or less is predicted between present and future ranges, and for three species no overlap is predicted at all (Birdlife, 2004a). Furthermore, even if overall climate space remains the same or expands, birds may still be forced to shift to unsuitable areas. See figure 5.

- The future distributions of 10 British Isles bird species were mapped using six climate variables. While some distributions are expected to remain unchanged or even expand, the model revealed: "serious negative consequences" for UK populations of willow tits; a "bleak" outlook for the UK populations of capercaillie with a reduction of 99 per cent of its current distribution; the loss of the south east England population of the nuthatch; decline of the red-throated diver; and possible disappearance of breeding snow buntings from Scotland's Grampians due to loss of suitable habitat (Berry *et al.*, 2001).

In the Pacific:

- In Hawaii, pastureland above a protected area (Hakalau Refuge) is expected to prevent the retreat of honeycreeper bird species upward in elevation to cooler

Table 6: Gross and net loss of neotropical migrant birds in the USA

Neotropical Migrants	Gross loss %	Net loss %
California	-29	-6
Eastern Midwest	-57	-30
Great Lakes	-53	-29
Great Plains - Central	-44	-8
Great Plains - Northern	-44	-10
Great Plains - Southern	-32	-14
New England	-44	-15
Pacific Northwest	-32	-16
Rocky Mountains	-39	-10
Southeast	-37	-22
Southwest	-29	-4
Mid-Atlantic	-45	-23
Based on U.S National Assessment Region modelling results from Canadian Climate Center's General Circulation Model (CCV-GCM2) climate data.		

Table 6: Gross and net loss of neotropical migrant birds in the USA under a scenario with a doubling of CO_2. "Gross" changes depict the overall loss of species currently found in areas, while "net" changes depict species loss from an area offset by species moving into the area from an outside region (from NWF/ABC 2002).

areas as their current forest habitat becomes unsuitable due to invasion by mosquitoes carrying avian malaria deadly to the honeycreepers (Benning *et al.*, 2002; see case study 4).

In North America

- In the USA, climate models suggest that unabated global warming will cause a net decrease in neotropical[7] migrant birds in every region. In the Great Lakes region, for example, although a 53 per cent loss of species is predicted to be somewhat offset by new species shifting into the region, a 29 per cent net decrease in neotropical bird species is expected (NWF/ABC, 2002).

In Africa:

- The cape longclaw is a fairly common endemic southern African bird found in grassland habitats from the coast to the highlands. Climate envelope models used moisture and temperature to map its future distribution, revealing the species would retreat southward as its range contracts considerably. It would be confined to higher ground in South Africa and would become locally extinct in Botswana (Birdlife, 2004a).

7 Species which breed in North America but migrate south to the neotropics of Central and South America, southern USA and Mexico.

CASE STUDY 3: NORTH AMERICA

Shrinking, shifting wetlands will reduce crucial duck habitat

The Prairie Pothole Region of the Northern Great Plains of North America is the most important breeding area for the continent's water birds, providing breeding habitat for between 50-80 per cent of the continent's ducks. It is also the most productive duck habitat in the world. Research on this area further illustrates the risk posed by human-induced climate change to wetlands.

Based on a doubling of CO_2 by 2060, a 2.5 °C temperature increase and no change in precipitation, researchers predict the number of ponds in this zone will be cut by two thirds (67 per cent), from the present 1.3 million ponds, depending on the climate scenario used (Sorenson *et al.*, 1998). As a result, duck numbers in north-central USA are expected to be reduced by almost three quarters (72 per cent), from the present five million.

These findings have been backed up by new research, which found that suitable waterfowl habitat in this region would be halved as early as 2050, and would shift to wetter eastern and northern fringes -- areas that are less productive or where most wetlands have been drained. According to Johnson *et al.* (2005), "Unless these wetlands are protected and restored, there is little insurance for waterfowl against future climate warming."

This work incisively demonstrates that "static" bird conservation efforts based on current protected areas will be undermined by climate change, and instead a dynamic approach will be required that incorporates protection and preparation of new climatically-suitable habitat.

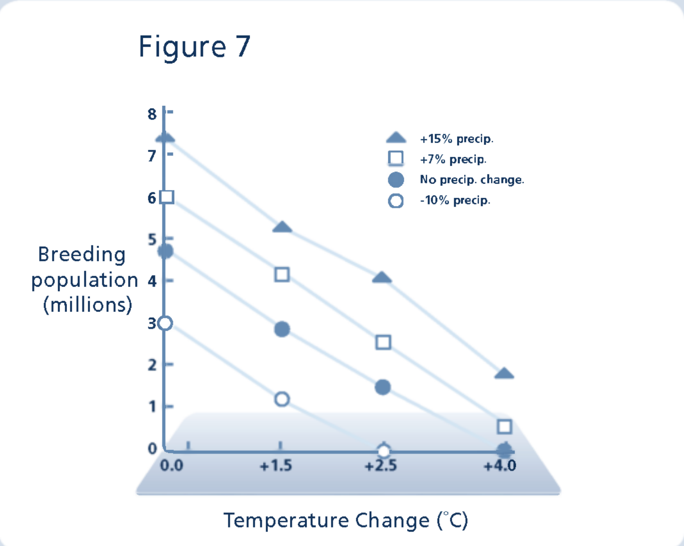


Figure 7: Projected duck breeding population sizes in the Northern Great Plains of the USA, as a function of climate warming.

Baseline population is five million (from Sorenson *et al.*, 1998).

4.2 How climate change will disrupt communities and ecosystems

"… well-balanced bird communities as we know them will likely be torn apart. As species move, they may have to deal with different prey, predators and competitors as well as habitats that are less than ideal."

Terry Root, Stanford University Center for Environmental Science and Policy (NWF, undated)

More frequent El Niños, a feature of climate change, make ocean prey unavailable to Galápagos penguins

When groups of plants and animals that make up an ecological "community" (a set of populations that inhabit a specific area) respond to climate changes by shifting their ranges, they do not shift intact. Rather the speed and distance each species shifts depends on its sensitivity to climate change, as well as its mobility, lifespan, and the availability of moisture and other needs (Hannah *et al.*, 2005; Root and Hughes, 2005; ACIA, 2004).

Thus with climate change, the makeup of communities will change as species track their climate space by shifting to new areas (Hannah *et al.*, 2005). As a result, the type and abundance of species upon which birds depend -- food sources such seeds, fruits, insects, as well as nesting materials -- may decline, affecting birds' health (NWF/ABC, 2002). These disrupted ecological communities mean birds may also face new competitors, predators, prey and parasites to which they are not adapted, and that "optimal" habitats for many species may disappear, at least for the short term (NWF/ABC, 2002; Benning *et al.*, 2002). As old ecosystems disappear and are replaced by new ones, the consequences are unknown and largely unpredictable.

This explains why changes in distribution caused directly by climate change, described in the previous section, appear to be just the start of a chain of effects. The resulting re-organised communities will in turn produce further distribution changes of their own, changes that are likely to be even more extreme (Peterson *et al.*, 2002; Davis *et al.*, 1998; Pounds and Puschendorf, 2004).

CASE STUDY 4: THE PACIFIC

Warming islands bring malaria to Hawaiian honeycreepers

Hawaiian honeycreepers, a type of finch, once numbered at least 29 species but are now down to 19 with past extinctions driven by habitat loss, introduced predators and disease (Benning *et al.*, 2002).

Introduced avian malaria played a large role in the decline of the birds, which are susceptible to the disease. The birds' current habitat is now mainly restricted to higher altitudes where malaria-transmitting mosquitoes are few or non-existent. These high elevation forests form a refuge for eight endangered honeycreeper species.

Research by Benning *et al.* (2002) shows that with 2°C of regional warming, a level in keeping with climate model predictions for the region, optimal habitat for the birds' three forest refuges would be reduced by half in the first refuge (Hanawi Forest), 96 per cent in a second (Hakalua), and completely eliminated in the third (Alakai Swamp).

Furthermore, the area above Hakalau Wildlife Refuge is used as pasture land, and this would prevent movement of forested honeycreeper habitat upslope. Under this climate scenario several of the remaining 19 honeycreeper species are expected to become extinct.

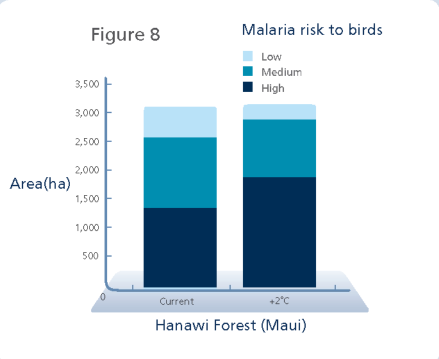
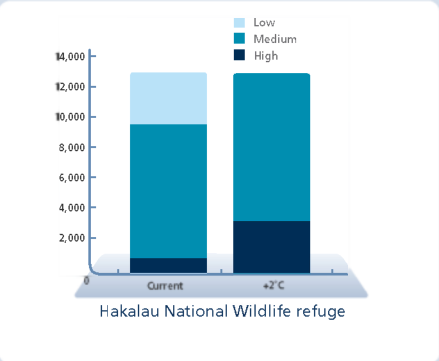
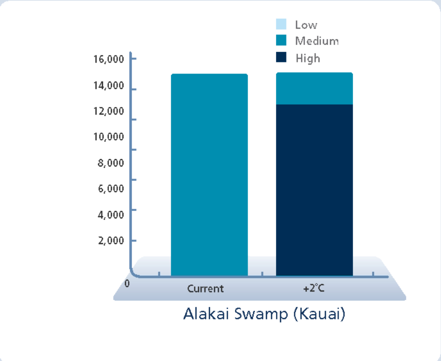


Figure 8: Invasion by malaria-carrying mosquitoes with climate warming will radically reduce the forest refuge of Hawaii's honeycreepers, and is expected to result in extinction of several species (Benning *et al.*, 2002).





The movement of communities due to climate change must be considered within the context that the required migration rates for plant species due to global warming appear to be historically unprecedented (WWF, 2002) and are 10 times greater than those recorded from the last glacial retreat. New data shows European birds will be subject to climatic changes of this magnitude, and that “boundary shifts are likely to be faster than many species are able to realize such boundary changes,” according to Huntley *et al.* (2006). Rates of change of this magnitude will likely result in extensive species extinction and local extirpations of both plant and animal species (van Vliet and Leemans, 2006).

This risk to biodiversity must also be considered in light of the extent to which climate change will alter birds’ habitats (see also section 2). In Eurasia alone, more than half of the existing habitat in Russia, Sweden, Finland, Estonia, Latvia, Iceland, Kyrgyzstan, Tajikistan and Georgia will be at risk from global warming, through outright loss of habitat or change into other types of habitat. “There is no certainty that similar or equally diverse ecosystems will establish themselves elsewhere” (WWF, 2000).

Climate change can also affect the incidence of disease in birds, by shifting the rate at which pathogens reproduce or affecting the distributions of the animals that carry disease. Reduced precipitation and greater drought is expected in some regions, and this could cause birds to accumulate around limited water resources, potentially increasing disease transmission and reducing their survival (BTO, 2002).

Thus climatically-induced shifts could easily “tear apart” communities of interdependent plants and animals (Root and Hughes, 2005). The relationships between predator and prey could become disconnected, and competition for survival between species could be pushed to new and different equilibrium points. These climatic changes in turn “would likely alter the structure and functioning of most, if not all, of the world’s ecosystems,” according to Root and Hughes (2005).

4.2.1 How birds are already affected by disrupted communities

This section shows how climate change is already affecting the interaction between bird species, their competitors, prey and parasites, using existing examples. Some examples also indicate the scale of future impacts, such as an expected 40 per cent species turnover for an entire ecological community in Mexico.

In Europe:

- In Germany, the number and proportion of long-distance migrants decreased and the number and proportion of short-distance migrants and resident birds increased between 1980 and 1992. Research suggests the effects could be explained by observed climate change, with the trend of warmer winter temperatures in this zone benefiting resident birds and increasing the competitive pressure they impose on long-distance migrants. Thus, "increasingly warmer winters pose a more severe threat to long-distance migratory species than to other bird groups," according to Lemoine and Böhning-Gaese (2003).

In North America:

- The first study to examine the effect of future climate change on a whole community in detail (including 1,179 bird species, 63 per cent of the total investigated) in Mexico predicted[8] that turnover among the species in some local communities would exceed 40 per cent by 2055 as dozens of species disappear or are displaced by invaders, suggesting that severe disturbance of ecological communities may result, according to Peterson *et al.* (2002).

- Brunnich's guillemots in Canada's northern Hudson Bay had greater egg loss and adult mortality during hot days when high numbers of mosquitoes were in the area. Mortality was worst at the edge of the colony where mosquito attacks were also worst. The dates of first appearance and peak abundance of mosquitoes have advanced since the mid-1980s, in conjunction with ongoing climate change, but the breeding seabirds have not yet adjusted their behaviour to adapt to this change in peak mosquito parasitism (Gaston *et al.*, 2002).

In Antarctica:

- At the Antarctic Peninsula, temperatures are rising relatively rapidly, a change researchers believe is due to global warming (Turner *et al.*, 2006; Cook *et al.*, 2005). This warming is thought to be shifting the makeup of the phytoplankton in the Antarctic food chain as glacial melt-water runoff increases and surface water salinity is reduced (Moline *et al.*, 2004), a trend expected to increase with further warming. This shift is causing a proliferation of salps, transparent jelly-like creatures that are not a preferred penguin food, and a reduction in krill, a keystone prey species of Antarctic animals including penguin species. Negative impacts on these birds are expected as a result.

5 How climate change affects population dynamics

"… the low end of the precipitation range brings the population near reproductive failure. Any change in climate that would increase the frequency of extreme dry conditions would likely endanger populations of these species."

Bolger *et al.*, 2005

Climate change is already affecting the dynamics of bird populations. This occurs because local weather and regional climate patterns have a strong influence on bird behaviour in both breeding and non-breeding seasons (Crick, 2004; Saether *et al.*, 2004). Because the size of a population depends on both survival through the

8 With 1.5 - 2.5°C of warming and a 70-130 mm decrease in precipitation.

non-breeding season and on breeding performance, the ultimate effect of climate change will depend on the relative impact upon of these two factors (DEFRA, 2005). How climate change effects interact with population density[9] will also be important (Saether *et al.*, 2004).

Taken as a whole, the vulnerability of birds in this respect is becoming clear. Research so far indicates that for birds whose offspring are born highly dependent (so-called altricial species[10]), climate change effects in the non-breeding season will be most important. For birds with precocious young (so-called nidifugous species[11]) and those breeding in arid environments, climate change effects during the breeding season will be more important (Saether *et al.*, 2004; Bolger *et al.*, 2005).

5.1 Climate change and the reproductive success of birds

"The 2004 breeding season is over, and the success rate this year is shocking: it's non-existent; complete failure, unprecedented in recorded times. The results from Orkney are coming in, too, and appear to be almost as catastrophic. The reason, most believe, is climate change"

Malcolm Tait on the 2004-05 breeding collapse of some UK seabirds colonies (Tait, 2004)

Climate change threatens Tufted Puffins at Canada's largest puffin colony

This section illustrates how climate change is affecting bird population dynamics by acting on factors such as nesting, clutch size, and fledgling survival as well as general reproductive success. These factors affect "new recruitment", the number of new individuals added to a given population.

In Europe:

- A trend of warm, sunny June weather linked with increased survival in spotted flycatcher offspring initially suggests that a warming climate could increase the productivity of some bird species; however these tendencies may not dominate in the short and long term to actually increase populations (DEFRA, 2005). Some pied flycatcher populations in Europe suffered from climate change, (see case study 1). Furthermore, climate change is predicted to bring wetter springs to some temperate zones, and this is expected to decrease chick survival rates in some species (DEFRA, 2005).

9 For example, changes in rainfall due to climate change could alter food availability. If a population is at a low density, it might be unaffected, but if it is at maximum density, climate change could affect the population via food scarcity (Saether *et al.*, 2004).

10 Birds whose young hatch with their eyes closed, naked or near naked, and are incapable of departing from the nest, and are fed by the parents.

11 Hatched with eyes open, covered with down, and can leave the nest immediately.

Figure 9

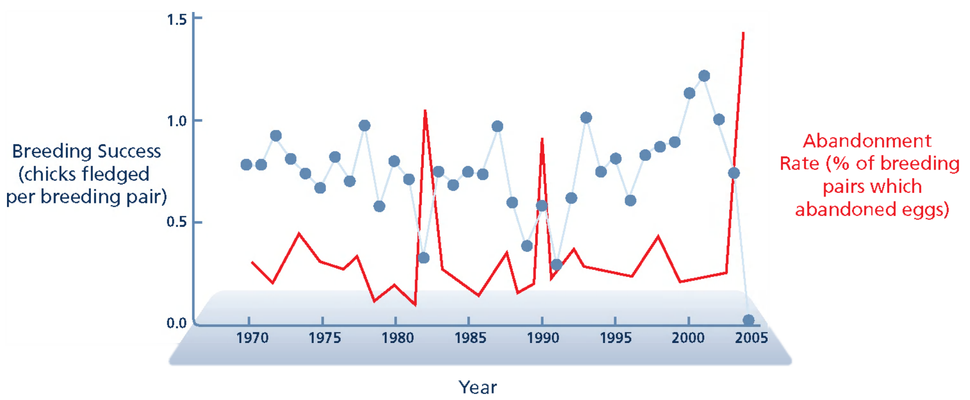


Figure 9. Southeast Farallon Island, California: Breeding success for Cassin's auklet (blue) and abandonment rate (red). In 2005 the breeding colony was abandoned *en mass*, an unprecedented event. From Sydeman *et al.* (in press).

In the Arctic:

- Approximately half of the Arctic breeding grounds of geese and Calidrid waders (migratory Arctic wading birds such as sandpipers) would be lost with a doubling of CO_2 by the period 2080 to 2099, according to UNEP. A simplistic extrapolation would suggest loss of breeding habitat for 4-5 million geese (down from the current 10.4 million) and 7.5 million Calidrid waders (currently 14.5 million; Zöckler and Lysenko, 2000).

In North America:

- In spring 2005, an unprecedented seabird breeding decline occurred on the continent's west coast, with bodies of Brandt's cormorants, dead from starvation, found in numbers up to 80 times higher than previous years in some areas, and decreased breeding recorded for common murres (guillemots) and Cassin's auklets (Parrish, 2005). Cassin's auklets at California's Southeast Farallon Island breeding colony abandoned the site *en masse* in May -- behaviour never witnessed in the 36 years of study there -- and completely failed to breed. In Canada, only eight per cent of Cassin's auklets nesting at the Triangle Island colony were successful, the worst year on record. A two month delay in northerly winds also delayed coastal spring upwelling of nutrient rich waters, radically reducing phytoplankton. Fish species that prey on the plankton also declined, as did the seabirds that prey on fish (Sydeman *et al.*, in press). According to Peterson (2005), "Since the upwelling season began so late, it was the mismatch between the expectation of birds and fish encountering abundant food and when the abundant food was actually present that explained the failure of birds and fish this summer." This illustrates the potentially profound ecosystem effects of shifts in ocean currents expected with climate change.

- Off Canada's west coast two decades of unusually warm temperatures associated with climate change between 1975 and 2002 led to

Figure 10

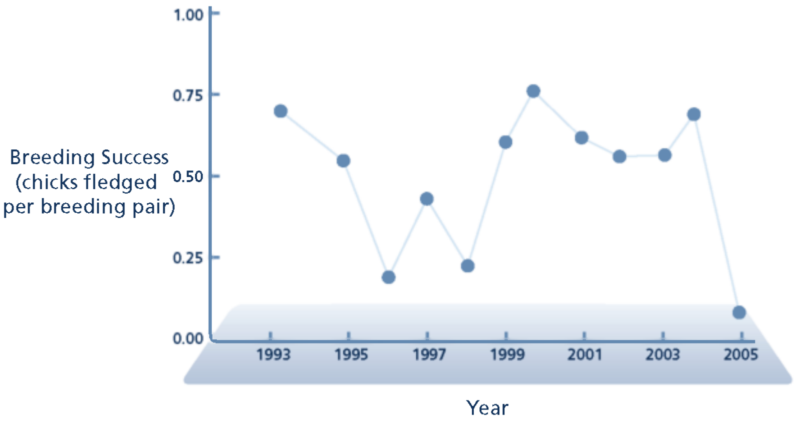


Figure 10: At Triangle Island, Canada only eight per cent of Cassin's auklets bred successfully in 2005, the worst year on record (Sydeman et al., in press).

drastically decreased growth rates and fledging success of tufted puffin nestlings, with fledging success near zero when waters were warmest; the birds are considered highly vulnerable to climate change, which could make the site of Canada's largest puffin colony unsuitable for breeding for this species (Gjerdrum *et al.*, 2003).

- In coastal southern California, the breeding success of four bird species (rufous crowned sparrow, wrentit, spotted towhee and California towhee) in semi-arid coastal sage scrub dropped to 3 per cent of its former level, from 2.37 fledglings per pair in 2001 (a normal year) to 0.07 fledglings per pair during 2002, the driest year in the region's 150-year climate record. Only 6.7 per cent of pairs attempted to nest that year, versus 88.4 per cent in 2001. While it is difficult to definitively link the 2002 drought to climate change, precipitation in this region is expected to decrease and become more variable with global warming. Even a modest increase in the frequency of arid conditions would make these species vulnerable to extinction in a dry year (Bolger *et al.*, 2005).

In South America:

- Endangered Galápagos penguin populations have halved since the early 1970s because the adult penguins become emaciated (sometimes dying) and fail to reproduce during severe El Niño years (Boersma, 1998). Populations dropped precipitously after the 1982-3 El Niño, and recovered only slowly. There are no suitable foraging areas for the penguins outside the Galápagos (Boersma, 1999). Because climate models predict El Niños to become more frequent in future (Timmerman *et al.*, 1999), climate change is expected to further reduce these small, restricted populations of Galápagos penguin and threaten them with extinction (Boersma, 1998).

In Australia:

- Abnormally high 2002 ocean surface temperatures at the southern part of Australia's Great Barrier Reef (GBR) altered the availability and accessibility of fish prey species for the region's wedge-tailed shearwaters. A strong relationship was shown between the unusually warm w aters, reduced ability of adults to provide for chicks, decreased chick growth rates, and reproductive failure. According to Smithers *et al*. (2003), "As SST [sea surface temperatures] continue to rise with global climate change, our results predict substantial detrimental effects on seabird populations of the GBR."

CASE STUDY 5: NORTH SEA

Unprecedented breeding failure of seabirds

Common guillemot, (*Uria aalge*)

In 2003 and 2004 news reports cited hundreds of dead seabirds, including guillemots, puffins, razorbills and fulmars washing up off Northern France, Belgium and coastal UK. In 2004 the Royal Society for the Protection of Birds (RSPB) reported that among six key North Sea seabird species nesting on Shetland and Orkney colonies, tens of thousands of these long-lived, slow breeding seabirds failed to raise any young; shortages of a prey species called sandeels is likely to be the direct cause (Lanchbery, 2005).

For example, on the Shetland Islands, 7,000 pairs of great skuas produced only a handful of chicks, while 1,000 pairs of Arctic skuas produced no surviving chicks at all for the 2004 breeding season. Starving adult birds ate those chicks that did hatch. Shetland's 24,000 pairs of Arctic terns and more than 16,000 pairs of kittiwakes are also thought to have suffered near total breeding failure (Lanchbery, 2005). According to the RSPB, populations of some species such as Arctic skuas are reaching critically low levels, with a bleak outlook for the future (RSPB, 2004d).

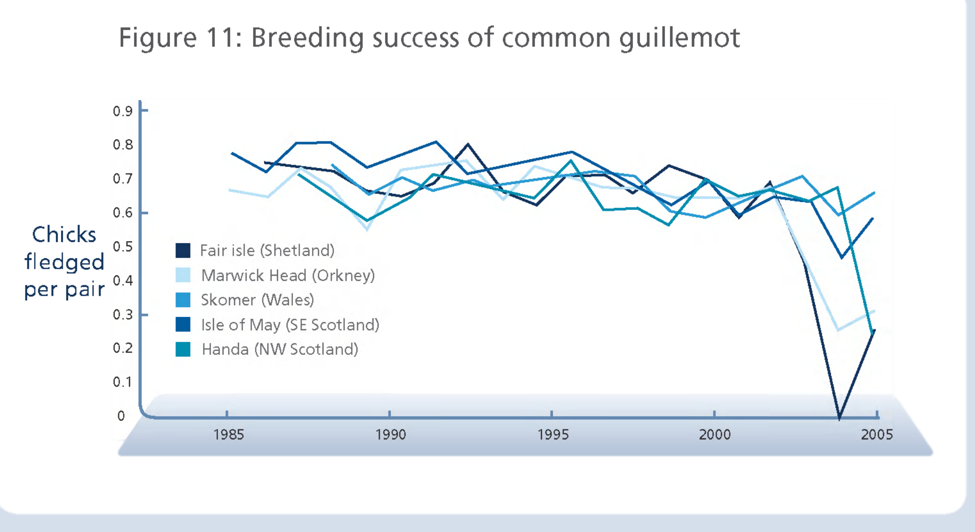
A partial recovery in productivity for North Sea birds followed in 2005 as sandeels returned. However, the scarcity of larger sandeels (those hatched in 2004) made it more difficult for adults to achieve breeding condition and resulted in one of the latest breeding seasons ever recorded. This delay resulted in starvation of some chicks, because sandeels become unavailable later in the season.

These events are still under investigation, however, researchers have linked this wide-spread breeding failure to a large-scale change in marine ecosystems in the North Sea, caused in part by climate change (Lanchbery, 2005). The shortage of sandeels is linked to both warmer waters and to reduced plankton abundance (Lanchbery, 2005; Arnott and Ruxton, 2002).

North Sea temperatures were significantly higher in 2003 and 2004 than the 30-year average (1961-1990). Climate change has caused North Sea temperatures to rise 1°C in the last 25 years -- a huge change for a marine ecosystem.

According to Lanchbery (2005), "In summary it would appear that a large-scale change in marine ecosystems is occurring in the North Sea, caused in part by climate change. The plankton regime most certainly has changed and it is hard to find an explanation other than sea temperature rise that adequately accounts for it. Sandeel numbers have declined and a change in sea temperature coupled with a change in the plankton population (also induced by a temperature change) seems a likely explanation."

Figure 11: Unprecedented decline in reproductive success in 2004 for some North Sea colonies of guillemots, followed by partial recovery in 2005. The breeding failures have been linked to food chain disruptions caused in large part by climate change (from JNCC, 2005).



5.1.1 A note about climate extremes

The above example on arid-land birds from California's southern coast shows the disastrous effect that extreme weather -- in this case the driest ever year in a 150-year climate record -- on avian reproduction (Bolger *et al.*, 2005). Increased frequency of weather extremes will negatively impact adult birds, as well as their young, in summer and winter (DEFRA, 2005). These events can dramatically reduce bird populations and recovery can be very slow.

The effects of climate extremes (more heat waves, storm events and droughts, and more variable temperatures) were described in detail in section 2, and here we additionally note that, according to van Vliet and Leemans (2006), "there will be large changes in the frequency and magnitude of extreme events and consequently, unpredictable, but devastating impacts on species and ecosystems even with a moderate climate change (an increase of 1 to 2°C)."

Ecosystems and birds within them are responding especially rapidly and vigorously to these large events (van Vliet and Leemans, 2006; Klein Tank, 2004), and this can explain the unexpectedly swift response to climate change seen in ecosystems worldwide (van Vliet and Leemans, 2006). Furthermore, failure to account for these effects means that projections, including those of the IPCC, are likely to underestimate future impact levels (van Vliet and Leemans, 2006).

5.2 The effects of climate change on adult survival

This section focuses on how climate change is influencing bird population sizes by affecting adult survival.

Migratory species in Europe and elsewhere will be vulnerable to climate impacts across all their habitats, including the Arctic, where such impacts are expected to be extreme. Migratory birds that breed in the UK and Europe but spend winter in Africa will be vulnerable to increased levels of drought predicted for the Sahel region of Africa (see section 6 for further details).

In cooler climates, winter survival is an important determinant of population. Thus the survival rate of some species in Europe has increased in recent decades with warming winters (see example below).

However, it is not yet possible to determine whether climate change will increase these bird populations overall (EEA, 2004) because the many variables involved make such effects complicated to predict. A population's adaptation to increased winter survival is flexible and depends on competition and predator/prey interactions. According to the European Environment Agency (2004), "Some species will benefit and their population will increase while others could be adversely affected". An example from North America (see below) illustrates how a climate change, in this case warming, can cause population increases followed by reductions as warming further impacts the birds' environment (Meehan, 1998).

In Europe:

- In France, pooled data on 77 terrestrial bird species revealed a "highly significant" 14 per cent decline in the overall abundance of this nation's bird population from 1989-2001, with climate change being "the likely cause of an important and rapid reduction of population abundance of several species," according to Julliard *et al.* (2003).

- Survival rates of five European bird species (grey heron, common buzzard, cormorant, song thrush and redwing) wintering in Europe have increased 2-6 per cent per 1˚C rise in temperature, most likely because foraging is easier (EEA, 2004). However, as outlined above, it is not yet possible to determine whether climate change will increase these bird populations overall (EEA, 2004).

- The numbers of adult whitethroat, a migratory bird that breeds in Britain but overwinters in Africa, decreased more than 90 per cent following a 1968 drought in the Sahel, and have still not recovered to their former levels (DEFRA, 2005). This illustrates the vulnerability of these European migratory birds to extreme events, and to increased levels of drought predicted for the Sahel region with climate change.

In North America:

- While warming temperatures linked to climate change initially allowed a black guillemot breeding colony to gain a foothold in northern Alaska in the 1960s, the continued effects of warming are now driving the birds away. The birds rely on small Arctic cod, which are found near pack ice. But in recent decades the ice has receded further offshore, making foraging difficult and resulting in reduced immigration of the birds and lower adult survival in some colonies (Meehan, 1998).

In the Southern Ocean:

- A radical, 94 per cent population crash of the rockhopper penguin at sub-Antarctic Campbell Island is attributed in part to warming climate conditions that are altering bird habitats (IPCC, 2001b). The penguin's numbers declined from 1.6 million in 1942 to 103,000 breeding penguins in 1985 (Cunningham and Mores, 1994) with the most severe phase of the decline coinciding with substantial shifts (warming) in December-February sea-surface temperature. In one colony, the penguin's numbers temporarily increased after the seas cooled temporarily. Cunningham and Mores (1994) conclude that "rising sea temperatures are associated with the decline, which may have been caused by changes in the penguins' food supply; there is no evidence that terrestrial factors have been responsible."

6 Climate change and bird extinction

"… anthropogenic climate warming at least ranks alongside other recognized threats to global biodiversity … [and] is likely to be the greatest threat in many if not most regions."

Thomas *et al.*, 2004

6.1 The scale of climate change risk to general biodiversity

Extinction, the demise of every last individual of a given species, is the most serious consequence of climate change for birds as a whole. Climate change has already caused well-documented cases of extinction of approximately 70 species of harlequin frogs in Central and South America (Pounds *et al.*, 2006), as well as the local extinction (extirpation[12]) of two checkerspot butterfly populations in California (McLaughlin *et al.*, 2002). With further climate change local and global extinctions are likely. This threat exists even for bird species currently considered of safe conservation status (Birdlife, 2004a).

As noted above, a key threat with anthropogenic climate change is the rapid rate of change, which leaves species little time to adapt (Leemans and Eickhout, 2004). In particular, species in some northern polar regions will be forced to adjust to rates of warming several times higher than mid-latitudes.

Thomas *et al.* (2004) were the first to broadly delineate extinction risk due to climate change. They reveal that with minimum expected levels[13] of global warming, 18 per cent of all terrestrial plants and animals could be committed to extinction by 2050; with moderate global warming this figure rises to 24 per cent; and with a maximum climate change scenario 35 per cent of all terrestrial plants and animals could be committed to extinction by 2050 (Thomas *et al.*, 2004). They find that in all, one million species may be committed to extinction by 2050.

Thomas *et al.* (2004) further state that "anthropogenic climate warming at least ranks alongside other recognized threats to global biodiversity ... [and] is likely to be the greatest threat in many if not most regions." Putting this threat into perspective, mid-range climate change scenarios are expected to produce greater extinction rates than habitat loss, currently deemed the top threat to biodiversity (Thomas *et al.*, 2004).

More recent work by Malcolm *et al.* (2006) focuses on biodiversity hotspots and finds that with a doubling of CO_2 in 100 years, projected extinctions ranged from 1 to 43 per cent of endemic plants and vertebrate species, with an average extinction of 11.6 per cent. This analysis revealed that "estimated global-warming-induced rates of species extinctions in tropical hotspots in some cases exceeded those due to deforestation, supporting suggestions that global warming is one of the most serious threats to the planet's biodiversity" (Malcolm *et al.*, 2006).

Although an analysis by Thuiller *et al.* (2005) on European plants finds lower extinction rates than Thomas *et al.* (2004), they nonetheless note that extinction risk from global warming may be large even under moderate climate scenarios. Under a high climate change scenario[14] they find a mean species loss[15] of 42 per cent and species turnover of 63 per cent, with the percentage of species loss exceeding 80 per cent in some areas (north-central Spain and the Cevennes and Massif Central in France).

12 Extirpations are localised or regional extinctions of populations. Extirpation is of concern because it can reduce the overall genetic diversity of a given species, since isolated populations may have unique genetic attributes not found in other populations elsewhere on the globe (DEFRA 2005). Extirpation is becoming increasingly common as habitat is carved up by human development, creating barriers that prevent mixing between populations.

13 In Thomas *et al.* (2004) projections for a minimum expected climate change scenario refer to a mean increase in global temperature of 0.8 - 1.7°C and in CO_2 of 500 p.p.m.; mid-range scenarios refer to global temperature increases of 1.8 - 2.0°C and CO_2 increases of 500 - 550 p.p.m.v.; and maximum scenarios to global temperature increases of >2.0°C and CO_2 increases >550 p.p.m.

14 A1-HadCM3: Concentrations of CO_2 increase from 380 ppm in 2000 to 800 ppm in 2080, and global temperature rises by 3.6 K.

15 "Species loss does not necessarily imply the immediate loss of a species from a site, rather it may imply a potential lack of reproductive success and recruitment that will tend to extinction on a longer time scale" (Thuiller *et al.*, 2005).

CASE STUDY 6 : EUROPE

World's largest grouse threatened with local extinction by 2050

The capercaillie is found throughout northern forests stretching from Scandinavia to Siberia and in highly fragmented populations in temperate mountainous areas of western and central Europe. The western and central European capercaillie distributions have undergone serious decline over the last century, with many populations at risk of local extinction.

The capercaillie is one of the UK's most threatened birds. Capercaillie numbers in the UK declined drastically from 10,000 birds in the 1970s to approximately 1,000 birds in the late 90s. By 2005 the population stabilised at around 2,000 birds. The bird is confined to Caledonian pinewood and conifer plantations mainly in the eastern Highlands of Scotland.

Climate change is already associated with poor breeding success of the capercaillie due to increasingly protracted spring warming (Moss, *et al.*, 2001). Wet summers, a feature of climate change in the UK, directly impact on this species because high rainfall reduces chick survival.

However, the bird will become increasingly threatened because its potential climate space is reduced under all climate scenarios, dropping by as much as 99 per cent from its current distribution in worst case scenarios of global warming (Berry *et al.*, 2001). This scenario could see the capercaillie disappear from its UK habitat by 2050.

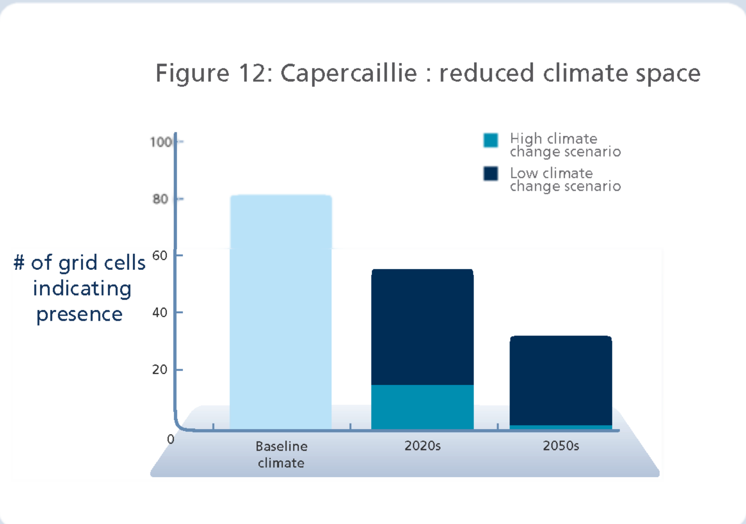


Figure 12: Projections showing habitat decline for the capercaillie in 2020 and 2050, under both low (0.9°C) and high (2.4°C) climate change scenarios.

The number of grid cells refer to areas of climatically suitable habitat.

6.1.1 Additional reasons for concern

"... many of the most severe impacts of climate change are likely to stem from interactions between threats ... rather than climate acting in isolation."

Thomas *et al.*, 2004

The risk of extreme weather events (see section 2.3 and 5), to which birds and other groups respond strongly, is a factor not included in many estimates of climate risk. Research that considers this risk finds that there are "many more reasons for concern" that will make it impossible, under rapid climate change, to uphold the UN Convention on Biodiversity's aim to stem the rate of biodiversity decline significantly by 2010 (van Vliet and Leemans, 2006; WWF, 2004).

In addition, climate change is also expected to interact with other human disturbances such as habitat loss and fragmentation (see section 4.1), species invasion and CO_2 buildup to disrupt communities and wipe out entire populations (Root *et al.*, 2003; Pounds and Puschendorf, 2004; Thomas *et al.*, 2004; Peterson *et al.*, 2002). The term "extinction spasm" has been used to describe the scenario posed by the additional threat of climate change when combined with current trajectories of habitat loss (Lovejoy and Hannah, 2005b).

Taken together, these factors explain why species are responding more strongly than expected from the average 0.8°C (Hansen *et al.*, 2005) of global warming that has occurred over the past century (Leemans and van Vliet, 2004). Therefore we may consider that current figures do not represent upper limits to extinction risk from climate change (Pounds and Puschendorf, 2004). However, the full consideration of risk to birds and other species due to climate change is extremely difficult to model, and is further complicated by the rarity of good datasets on wildlife (EEA, 2004).

6.2 Estimating the scale of extinction risk to birds

"Climate change will result in many extinctions … Both local and global extinctions are likely, even of species currently considered safe."

Birdlife, 2004a

As discussed above, evidence is mounting that some bird species may be unable to adapt to climate change because of direct climate effects, alteration of their habitats, phenological mismatch or miscue, range shifts and contractions, and the disruption and "tearing apart" of ecosystems. These threats put bird species at risk of extinction. But what level of risk can we expect?

As yet there are no global-scale studies providing a comprehensive assessment of extinction risk to birds from climate change. However, the biodiversity extinction analysis described above by Thomas *et al.* (2004)

includes projections of extinction risk for endemic bird species in European, Mexican, Australian and South African sample regions, based on data from regions of high biodiversity over 20 per cent of the earth's surface. This data is given in the following regional case studies, along with additional regional research and examples of extinction risk to individual bird species or groups, where possible.

Many extinction estimates are separated into projections that allow for species dispersal (a shift to new ranges), and those that assume no dispersal is possible. Real world outcomes are more likely to lie between these two scenarios (Thomas *et al.*, 2004).

6.2.1 REGIONAL CASE STUDY

Extinction risk for European birds

Of Europe's 524 bird species, 226 have unfavourable conservation status, with the outlook for many populations declining over the past decade (Birdlife, 2004b).

In terms of the threat from climate change, Europe has warmed more than the global average, with a 0.95°C increase since 1900. The warming has been greatest in north-west Russia and the Iberian Peninsula (EEA, 2004). In future, the worst impacted Eurasian countries will be Russia, Sweden, Finland, Estonia, Latvia, Iceland, Kyrgyzstan, Tajikistan, and Georgia, each with more than 50 per cent of existing habitat at risk through either complete loss or via change into another habitat type due to climate change (WWF, 2000). Mediterranean Europe is also identified as likely to suffer hotter, drier summers towards the end of the century (IPCC, 2001b). As noted in previous sections, climate change is already affecting birds in Europe. In Central Europe it has already been found to be a more important determinant of bird population trends than land-use change and "... climate change might be currently the most important threat for birds in Europe" (Lemoine, 2005).

Huntley *et al.* (2006) find that the threat to European birds posed by shrinking and shifting climate space is substantial, particularly for species that are highly specialised and restricted in their distribution. With warming by 2100 of approximately 2.5°C, species richness for 426 bird species native to Europe as breeding species is reduced by 8.6 per cent under the most optimistic scenario, which assumes all species will be able to shift to new climatically suitable ranges. The pessimistic scenario assumes birds are unable to shift at all and finds species richness would decline to 60 per cent of its current levels (Huntley *et al.*, 2006). These estimates do not allow the possibility of bird species shifting into Europe from Africa but find that even if this did occur, it "will not alter the general pattern of declining species richness in southern Europe," according to Huntley *et al.* (2006).

The birds most at risk of regional extinction in Europe were 19 species with zero potential future climatically suitable range under at least one climate scenario; another ten species have potential future distributions of 10 per cent or less than that of present. (None

Figure 13

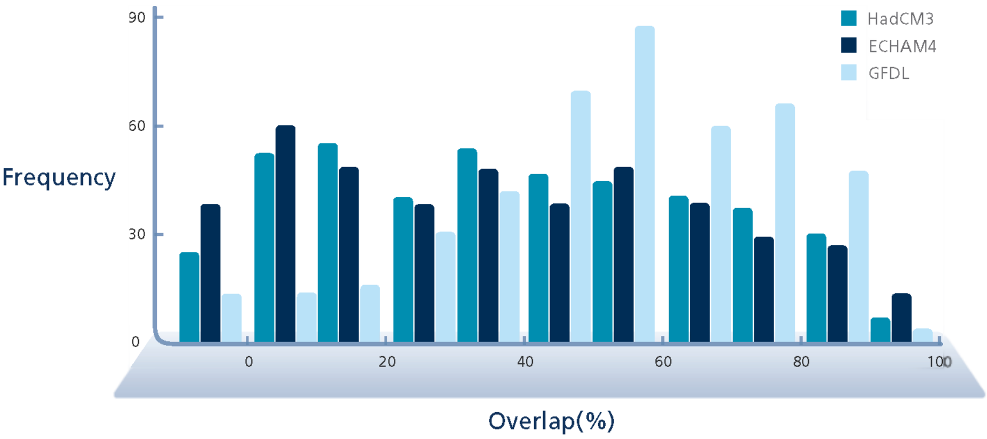


Figure 13: Frequency plot showing percentage overlap between present and future breeding distributions of 426 European-breeding bird species under three climate scenarios. Note many more species are projected to have zero overlap (left side) than are expected to have 90 per cent or greater overlap (right side). From Huntley *et al.*, 2006.

of these 29 species are endemic to Europe, however.) Overall, 25 per cent of the species breeding in Europe today have less than a 10 per cent overlap in their present and future distributions or future distributions that are less than 10 per cent that of present (Huntley *et al.*, 2006).

Research noted in section 4 (Birdlife, 2004a) found that for eight species of endemic European birds, there is less than 20 per cent overlap between current and future ranges, according to climate models; and for three of these species the overlap was zero. Examples below elaborate on the serious climate risk to such endemic birds, including the Scottish crossbill and Spanish imperial eagle.

Separate global warming extinction risk projections from the Thomas *et al.* (2004) meta-analysis described above reveal that 4-6 per cent of endemic European birds could be committed to extinction under a maximum climate change scenario, provided bird species are able to disperse freely. If no dispersal is possible[16], the number of species committed to extinction jumps to 13-38 per cent (depending on the method of calculation used[17]) under a climate change scenario with a global temperature increase of >2°C.

It is not possible to accurately estimate the extent to which these forecasts can be applied to groups outside the study areas and non-endemic birds. However, for a crude first order estimate, if the extinction rate of 38 per cent were applied to Europe as a whole, it would indicate a climate-induced extinction or extirpation on the level of 200 bird species. This broad brush figure is useful in so far as it tells us that extinction levels from climate change will not be a handful of birds, but that with high estimates of global warming the local, regional or total extinctions of dozens of bird species in Europe[18] is plausible.

16 Regarding dispersal ability, as mentioned above, the reality for most species is likely to exist somewhere between the two extremes of complete dispersal or non-dispersal.

17 Method one uses changes in the summed distribution areas of all species. Method two uses the average proportional loss of the distribution area of each species. Method three considers the extinction risk of each species in turn. For a more detailed description, see Thomas *et al.* (2004)

18 Note that caution must be applied in converting per cent extinction to number of species: Thomas *et al.* (2004) based their research on endemic species; however, because many of the total number of European species will be found elsewhere, the fixed number could be more acurately said to represent regional (European) extinction rather than total extinction.

Figure 14: European birds

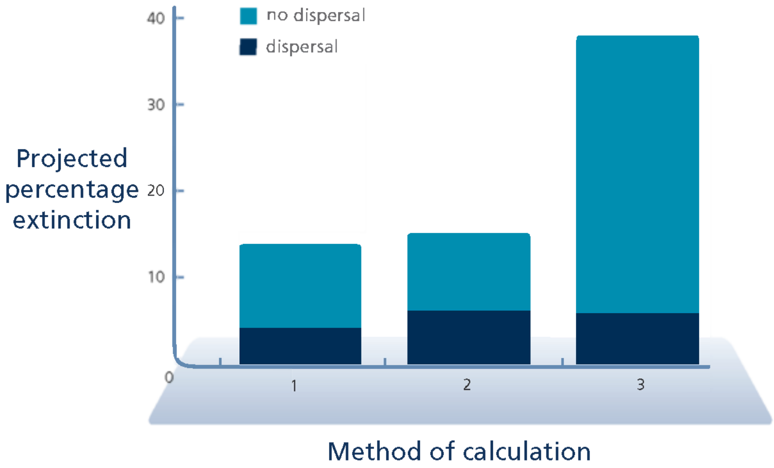


Figure 14: Estimates of extinction in Europe for a maximum climate change scenario range from 13 to 38 per cent if bird species are unable to disperse to new climatically suitable habitat. Vertical bars indicate percentage of bird species expected to become extinct in Europe with >2°C of global warming, according to three different methods of calculation (see above note). Inability to disperse (medium blue) is indicative of a much higher rate of extinction rate than if dispersal is possible (dark blue). Data from Thomas *et al.* (2004).

Thomas *et al.* (2004) indicate European birds might have lower than average risk of extinction from climate change than some other regions these authors examined. However, others including Julliard *et al.* (2003) note that because "climate change occurs in addition to global land use change, there is in fact little reason to be too optimistic." This is particularly true in Western Europe, which is under the double negative influence of climate change and land use change (Julliard *et al.*, 2003; Huntley *et al.*, 2006). Indeed accurately predicting extinction rates in Europe is highly complicated by its heavily populated and intensively managed landscape. As noted in section 4, in addition to facing natural barriers (mountains, water bodies and large arid zones) birds may be unable to shift to areas that are urbanised, used for agriculture or otherwise intensively managed, or are polluted or unprotected. If they unable to shift, they may face extinction (Huntley *et al.*, 2006; Birdlife, 2004a).

Data in Figure 15 below further illustrates how dispersal ability affects the vulnerability of Europe's top ten climatically endangered bird species. Authors Thomas *et al.* (2004b) note that, "Future studies that take account of the availability of natural areas are likely to result in even higher estimates of extinction rate."

Some European birds at risk of extinction:

- Marmora's warbler is under high threat from climate change. With a current population of about 30-50 thousand pairs, this small bird breeds on western Mediterranean islands and winters in Northern Africa. Unless it can disperse elsewhere, it faces complete loss of its habitat with climate change (Huntley *et al.*, 2006), a victim of the hotter, drier weather expected in the Mediterranean due to global warming.
- The endangered Spanish imperial eagle is restricted largely to natural

Figure 15

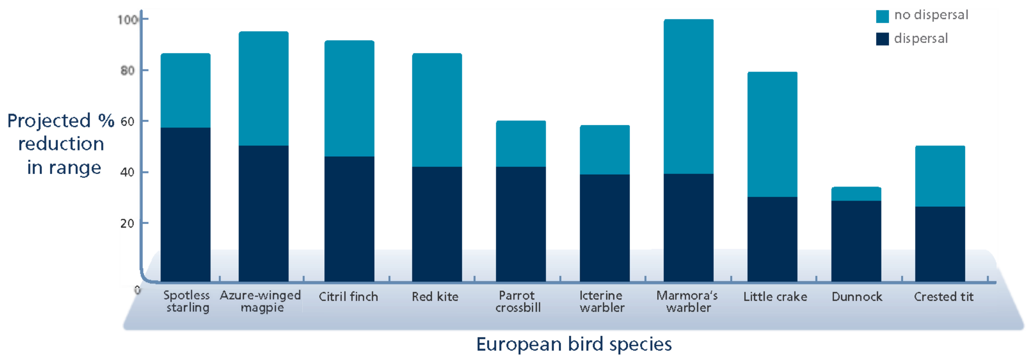


Figure 15: Projected per cent range reductions for Europe's top 10 climatically threatened bird species under a maximum climate change scenario. Note potential future range is highly dependent on birds' ability to disperse (from Thomas *et al.*, 2004b). Yet Europe's intensively managed, heavily populated landscape could pose major barriers to dispersal (RSPB/WWF, 2003).

parks and reserves, mainly in Spain but also in Portugal and Morocco. Climate scenarios predict that its entire current habitat will become unsuitable (Huntley *et al.*, 2006). Even though new climatically suitable areas are expected to be even larger than its current habitat, there may be insufficient undisturbed and protected areas available to support it -- an example of the barriers European bird species face as climate change forces distribution shifts complicated by land use factors.

- The red kite, a medium-sized raptor, will suffer up to 86 per cent loss of habitat due to climate change. It is an almost exclusively European species, with the possible exception of some populations of uncertain status in Northern Mediterranean Africa. It is currently severely threatened by habitat loss and other human impacts over much of its European range. Its survival already largely depends on conservation management and protected areas (Thomas *et al.*, 2004b).

- The Scottish crossbill will lose 100 per cent of its range because the climate of its current Scottish highland habitat will change substantially by the end of the century due to climate warming, according to Huntley *et al.* (2006). By that time, the climate currently experienced by this bird in Scotland will only be found in Iceland. Unless it can relocate or adapt to conditions it has never experienced in Scotland, these researchers find it will be at "extreme risk of global extinction as a result of climate change."

- Species at most immediate risk of extinction in the UK are those that breed in Arctic-alpine habitat in Scotland. This includes snow buntings and dotterels. As temperatures rise with climate change, lower-altitude vegetation will move up-slope and encroach on this already scarce habitat. With no higher altitude ground to move to, UK Arctic-alpine habitat will start to decrease and may disappear completely by 2050 (RSPB, 2004b).

Figure 16: Mexican birds

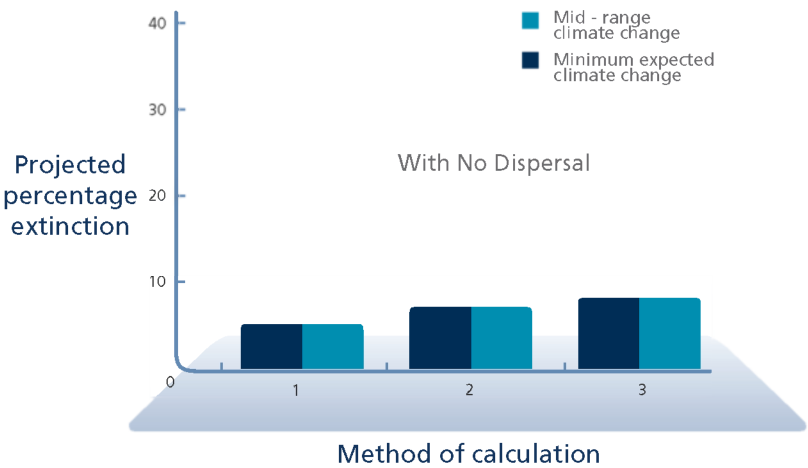


Figure 16: Extinction risk to Mexican bird species if no dispersal is possible, given a minimum and mid-range climate scenario, both of which predict the same level of extinction risk. Methods of calculation are the same as described above. Data from Thomas *et al.* (2004).

6.2.2 REGIONAL CASE STUDY

Extinction risk for Mexican birds

"Although only limited numbers of species will face entirely unsuitable conditions for persistence, others will experience drastic reductions and fragmentation of distributional areas, or extend their distributions, creating new natural communities with unknown properties… severe ecological perturbations may result."

Peterson *et al.* (2002) on a climate change scenario for Mexico

Mexico's high habitat biodiversity supports 11 per cent of the world's bird species, numbering 1,060 species. Ten per cent of these bird species are endemic (Bogart, 1998).

Thomas *et al.* (2004) provide data for bird extinction risk due to climate change in Mexico, based on work by Peterson *et al.* (2002). Assuming dispersal is possible, 2-3 per cent of bird species are predicted to become extinct under a minimum climate scenario (0.8 - 1.7˚C), and 3-4 per cent under a mid-range climate scenario (1.8 - 2.0˚C). Under the "no dispersal" scenario, both minimum and mid-range climate scenarios provide an extinction risk of 5-8 per cent (see Figure 16).

Local extinctions are predicted to be particularly high in the Chihuahuan desert. The above analysis confirms that flat regions of the world may be vulnerable to species loss if even a small change in climate requires many species to disperse massive distances to find new climatically suitable habitat (Peterson *et al.*, 2002).

Peterson *et al.* (2002) further note that species turnover in some areas of

Mexico will be greater than 40 per cent, and state that, "Although only limited numbers of species will face entirely unsuitable conditions for persistence, others will experience drastic reductions and fragmentation of distributional areas, or extend their distributions, creating new natural communities with unknown properties" and that "severe ecological perturbations may result." This additional risk of "reshuffled communities" is discussed in detail above (section 4.2).

Mexican and southwestern US bird species at risk of extinction:

The cape pygmy owl is a Mexican bird threatened by climate change. This bird is geographically isolated to the tip of Baja California in the Sierra de la Laguna pine and pine-oak forest at 1,500 - 2,100m, and deciduous forest down to 500m in winter. The Goldman's song sparrow and Baird's junco are other climatically threatened bird species found in Mexico (Thomas *et al.*, 2004b).

The southwestern willow flycatcher is an endangered species that breeds along rivers, streams, or other wetlands in southwestern US states and Texas. Its numbers have plummeted in the last century as a result of habitat destruction. Global warming is expected to contribute to hotter, drier conditions in this region, and this could cause the species to become extinct as more of its fragile habitat is lost. The golden-cheeked warbler and the black-capped vireo are two other endangered bird species that face a similar threat (NWF/ABC, 2002).

6.2.3 REGIONAL CASE STUDY

Extinction risk for Australian birds

"Extinction rates caused by the complete loss of core environments are likely to be severe, non-linear, with losses increasing rapidly beyond an increase of 2.0°C of warming..."

Williams *et al.* (2003) on risk to birds of Australia's Wet Tropics

Australia has 740 extant native bird species,[19] of which 98 are nationally threatened. Due to their evolving in relative geographic isolation, approximately 40 per cent of Australia's bird species are endemic (Department of Environment and Heritage, 2004).

Ecosystems particularly sensitive to climate change include Australia's high altitude mountain areas, due to projected reductions in winter snow cover; and highland northern Australian rainforests which are projected to decrease in area by 50 per cent with less than a 1°C increase in temperature (CSIRO, 2006). Thomas *et al.* (2004) give estimates for extinction risk within the latter zone, a region of high biodiversity in Australia's northeast, known as the Australian Wet Tropics. The level of extinction risk is comparatively high: 7-10 per cent extinction under a minimum climate scenario (0.8 - 1.7°C global temperature increase), and 49-72 per cent under a maximum climate scenario (>2.0°C global temperature increase).

19 A further 21 Australian bird species are presumed extinct.

Figure 17: Australian birds (Wet Tropics Bioregion)

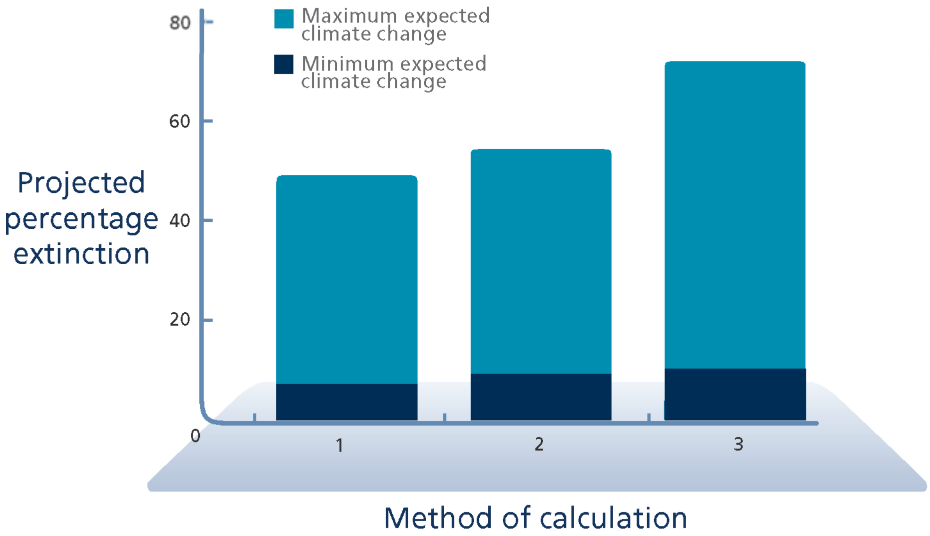


Figure 17: Extinction risk for birds in Australia's Wet Tropics Bioregion with dispersal, under both a minimum and maximum climate change scenario. Methods of calculation are the same as described above. Data from Thomas *et al.* (2004).

Related research by Williams *et al.* (2003) on the Australian Wet Tropics bioregion finds: "Extinction rates caused by the complete loss of core environments are likely to be severe, non-linear, with losses increasing rapidly beyond an increase of 2.0°C of [global] warming and compounded by other climate-related impacts."

New research also finds that up to 74 per cent of rainforest birds in north-eastern Australia will become threatened (including 26 species now critically endangered) as a result of mid-range (3.6°C of regional warming) climate change within the next 100 years (Shoo *et al.*, 2005a).

Upland birds are expected to be most affected, as they are most likely to be immediately threatened by even small temperature increases (Shoo *et al.*, 2005a). These conditions are creating what scientists have called an impending environmental catastrophe (Williams *et al.*, 2003).

Some Australian bird species at risk of extinction:

- The golden bowerbird occupies cool habitat in Australia's Wet Tropics, on conical mountains surrounded by warmer lowlands. As temperatures rise and its suitable habitat contracts, the climate envelope of this endemic bird is predicted to shrink from 1564 km^2 to just 37 km^2 (a 97.5 per cent reduction), restricting it to two mountain tops under a scenario with 3°C of future warming, assuming a 10 per cent decline in rainfall. Its habitat is to completely disappear with between 3 and 4°C of warming (Hilbert *et al.*, 2004).

Figure 18

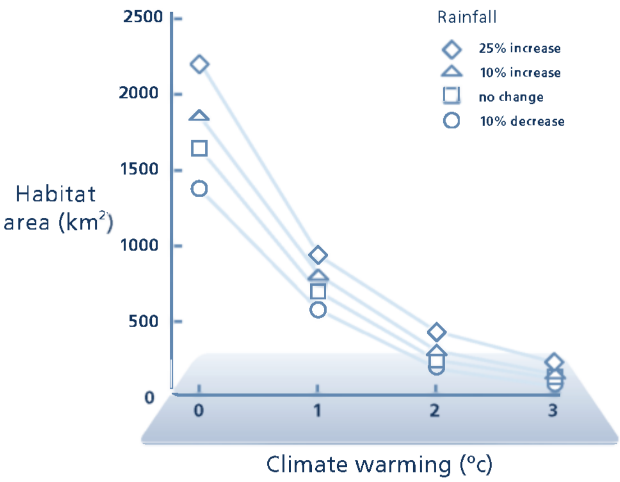


Figure 18. Predicted area of golden bowerbird habitat in a number of future climate change scenarios, including a range of changes in rainfall, and from 1 to 3˚C of warming (Hilbert *et al.*, 2004).

- Climate projections of a 3˚C temperature increase, along with a 10 per cent decrease in rainfall find that the bioclimates of three bird species will disappear from the southeastern state of Victoria: the Western whipbird, mallee emu-wren and the helmeted honeyeater, with seven other species "severely affected" by loss of their bioclimate (Chambers *et al.*, 2005).

6.2.4 REGIONAL CASE STUDY

Extinction risk for South African birds

South Africa has more than 951 bird species (Birdlife, 2006), 35 of which are threatened (Birdlife, undated). In general there is poor documentation on South African fauna's responsiveness to climate change (Erasmus *et al.*, 2002), even though Africa has been identified as the continent most at risk from climate change, in part due to its aridity (IPCC, 2001b). Africa is expected to become dryer still, with higher temperatures, more weather anomalies, more frequent El Niños and more fires (IPCC, 2001b).

In general, the distributions of birds in southern Africa are expected to become more restricted and contract towards the Cape with global warming (Huntley *et al.*, 2006). According to Lovejoy and Hannah (2005a) "at least one of the world's biodiversity hotspots, the Succulent Karoo in southern Africa, is likely to be massively and negatively affected at the double pre-industrial level [of CO_2]." Under mid-range climate scenarios the Succulent Karoo and Nama (another arid biome) are expected to be greatly reduced and shift to the southeast (Simmons *et al.*, 2004). These areas are home to 76 per cent of southern Africa's endemic birds.

A study of a variety of animal groups, including birds, found that climate change would result in range contractions for the vast majority (78 per cent) of species and that overall 2 per cent of the species would become

Figure 19: South African birds

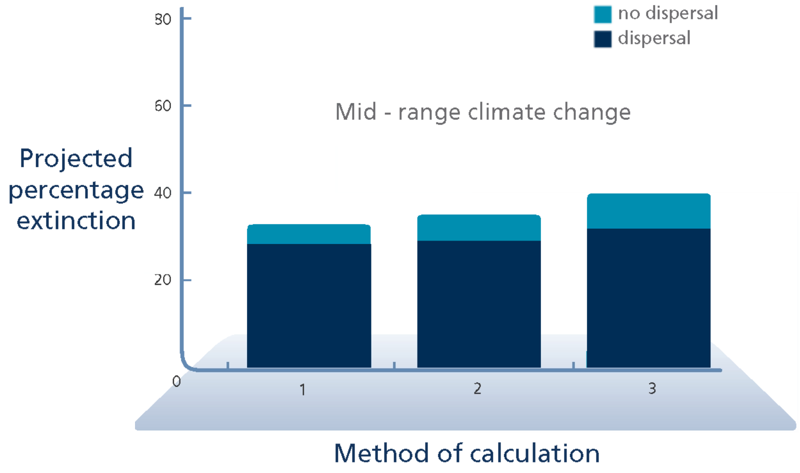


Figure 19: South African birds face comparatively high rates of risk from a mid-range climate scenario, even if dispersal is possible (dark blue). Methods of calculation are the same as described above. Data from Thomas *et al.* (2004).

locally extinct with a 2.5-3.0 °C regional temperature increase by 2050. This analysis by Erasmus *et al.* (2002) concludes that "climate change will have a profound impact on terrestrial animal species in South Africa".

Thomas *et al.* (2004) project a relatively high extinction risk due to climate change for birds in South Africa. The risk is 28-32 per cent for a mid-range climate change scenario (1.8 - 2.0°C of global warming) allowing for dispersal, and 33-40 per cent for a mid-range climate change scenario with no dispersal.

Illustrating the severe blow climate change can deal to current conservation efforts, major protected areas in the region, including Kruger National Park could lose up to 66 per cent of the species they currently protect (Erasmus *et al.*, 2002). Also of concern are findings that under a climate change scenario (doubling of pre-industrial levels of CO_2), those areas expected to have the most bird species are also projected to have the most dense human populations. This is because both human density and species richness in South Africa are associated with water availability, which is expected to decline in southern Africa. According to van Rensburg *et al.* (2004), "This means that there is substantial scope for conservation conflicts in the region..."

In Africa:

- The tawny eagle is an arid savanna raptor found in Asia and Africa. Projections show that even small changes in precipitation predicted with climate change would likely result in the birds' extinction in its African arid savanna habitat in the southern Kalahari (Wichmann *et al.*, 2003). Even if mean annual precipitation stays the same, but the inter-annual (year to year) variation increases just slightly -- by less than 10 per cent -- the bird's populations will decrease considerably.

6.3 Bird groups most at risk of extinction from climate change

"A global average temperature rise of 2°C in the next century will lead to numerous extinctions, but leave open some practical management options for the conservation of biodiversity. Temperature rises beyond this level are predicted to lead to catastrophic extinction rates, with few management options and a bleak future for both biodiversity and people."

Birdlife, 2004a

Generally speaking, species most vulnerable to extinction are those with restricted ranges or bounded distributions, such as those on the edge of continents, on mountain-tops or small islands. Poor dispersal ability, small populations or already poor conservation status additionally increase extinction risk. Birds breeding in arid environments are also at high risk (Bolger *et al.*, 2005; Reid *et al.*, 2005).

According to Chris Thomas of Leeds University, "mobile generalists may continue to prosper, whereas specialists are likely to continue to decline under the combined onslaught of habitat loss and climate change" (from RSPB/WWF, 2003). Climate change is also expected to cause invasive species to out-compete native species, because invaders can expand their ranges quickly or tolerate wide-ranging conditions (RSPB/WWF, 2003). Many of these factors are behind the heightened extinction risk for particular groups of birds described in the following sections: migratory species, wetland, coastal and seabirds, mountain and island birds, and Antarctic and Arctic species.

6.3.1 Migratory birds

"Migratory species, because they rely on spatially separated sites and habitats, may be especially vulnerable to the impacts of climate change, as change in any one of the sites used during the course of the annual cycle could have population impacts."

DEFRA, 2005

Eighty-four per cent of bird species listed with the Convention on the Conservation of Migratory Species (CMS) face threats from climate change. In fact, the threat of climate change to migratory birds has been deemed equal to the sum of all other human-caused threats combined (DEFRA, 2005). This high level of threat occurs because climatic change may affect these birds in their wintering areas, along their migration routes and in their breeding grounds (Aloha *et al.*, 2004). Indeed they are exposed to the summed climatic risk for each habitat used along their migration path, and the total effect could prove catastrophic (Huntley *et al.*, 2006).

Climate change is likely to affect the staging, stopover ecology and fuelling of migratory birds (DEFRA, 2005). Obtaining food for fat reserves, before and during the journey is important because migration is energetically costly (Bairlein and Hüppop, 2004). Yet changes in prey abundance due to climate change will affect more than 25 per cent of migratory species listed on the CMS (DEFRA, 2005).

As discussed in section 3, climate change is expected to make long-distance migrants more vulnerable than short-distance migratory birds due to the great risk to the former of mismatch between arrival time in breeding grounds and peak food availability there. Long-distance migrants could also be less adaptable to climatic change (Bairlein and Hüppop, 2004). Furthermore, long distance migrants often rely on a few particular stopover sites, employing predictability as a tactic to guide them to high quality feeding areas. Yet formerly dependable sites may deteriorate due to drought and vegetation shifts from climate change. In the face of such unpredictability, birds making long flights with few stopovers would be more vulnerable than those migrating in short hops (Bairlein and Hüppop, 2004).

Of European birds, those on the western European-African flyway appear to face the most severe consequences of climate change. This is because southern Spain, Northern Africa and the Sahel region of Africa, important stopover sites on this route, will undergo the most severe changes, i.e. desertification or conversion to drier habitats. For example, the annual rate of desertification in the Sahel is 80,000 km^2 per year (or 0.5 per cent; Bairlein and Hüppop, 2004). This means migratory birds may need to cross more hostile habitat, with staging areas becoming smaller and more spread apart. Such changes in water regime have been called the most widespread threat faced by migratory species (DEFRA, 2005). "Thus questions arise whether migratory birds from Europe are able to accommodate such changes," according to Bairlein and Hüppop (2004).

This is of heightened concern if climate change causes the distance between birds' breeding and non-breeding ranges to increase, as modelling indicates will be the case for many migrants between Europe and Africa (Huntley *et al.*, 2006). If longer migrating distances are "coupled with the loss of a critical stopover site the results for a species might be catastrophic," according to Huntley *et al.* (2006).

Migratory birds may also be adversely affected by changes in wind patterns and increased frequency of extreme events such as storms. Increased frequency of storms in the Caribbean already appears to be reducing the number of passerine[20] birds reaching their breeding grounds (DEFRA, 2005). Such new weather-related threats are potentially serious for species already pushed to their physiological limit by their migratory journey, including the red knot and bar-tailed godwit, both of which winter in Europe (DEFRA, 2005).

20 The Passeriformes are the very large order of "perching birds" or "song birds", which include flycatchers, wrens, swallows, waxwings, robins and mockingbirds, to name just a few.

Predicting the individual responses of different species to a wide array of habitat changes on migration routes spanning the globe is difficult and is hindered by uncertainty in models and a lack of detailed studies (Barlein and Hüppop, 2004). According to Saether (2000), "One frightening consequence of these findings is that they illustrate how difficult it will be to reliably predict the effects of large-scale regional climate change on ecological systems."

6.3.2 Wetland birds

"Given the potentially serious consequences of global warming for waterfowl populations ... society has yet another reason to act to slow greenhouse warming and safeguard the future of these resources."

Sorenson *et al.*, 1998

Under 3-4°C of warming, 85 per cent of all remaining wetlands could be eliminated (UNEP, 2005) -- a radical alteration of wetland birds' current habitat. Some European coastal areas, for example, are forecast to loose up to 100 per cent of their wetland stock by 2080 (IPCC, 2001b). As a result of these changes, 40 per cent of migratory bird species face impacts from predicted lowering of water tables, 53 per cent from changes in water regimes overall. As noted above, these changes in water regimes are actually the most widespread climatic threats to migratory bird species (DEFRA, 2005).

Remaining wetlands will face an increasingly variable hydrological cycle, which would leave inland wetlands to dry out, resulting in lower species diversity (see case study 3). Coastal marshes will also be affected, due to rising sea-level and changes in hydrological balance and severity. As noted in Section 2, habitat in estuaries and deltas will be lost if barriers prevent a natural retreat as sea levels rise (coastal squeeze; UNEP, 2005; IPCC 2001b). One of the most severe threats to birds, this is a particular problem in Europe where landward extension of salt marshes is restricted by hard sea defences, for example by dams and dykes in the Wadden Sea (Böhning-Gaese and Lemoine, 2004; Bairlein and Hüppop, 2004).

In the Arctic, permafrost melting will cause lakes and wetlands to drain in some areas, while creating new wetlands in others. The balance of these effects is unknown, but major species shifts are likely as a result (ACIA, 2004).

CASE STUDY 7

Declining Siberian crane faces threats in all habitats

The Siberian crane, a critically endangered species numbering 3,000 individuals, demonstrates the vulnerabilities of a wetland migratory bird to climate change. It breeds in Arctic Russia and Siberia and winters in China in the middle to lower reaches of the Yangtze River; a second population with just 3-8 individuals breeds in Iran; and a third population, now thought to be extirpated, once wintered in India. In addition to wintering in wetlands, the birds breed in wide open Arctic tundra and taiga[21] wetland in landscape that provides good visibility.

Arctic permafrost currently keeps the tundra treeless, but this bird's habitat is forecast to decline by 70 per cent with global warming, as trees colonise its habitat; adverse effects on its population are expected as a result (DEFRA, 2005).

Furthermore, precipitation has decreased in the bird's wintering grounds in China since 1965, especially during the last two decades. Yet when rainfall events do occur, they are more intense. Thus both drought and severe floods are more common, patterns likely to have adverse effect on Siberian cranes. Droughts dry up wetlands for extended periods, affecting food supplies. Intense rainfall events bring higher water levels. While the cranes can shift to areas of appropriate depth, the plants they feed on are less able to quickly shift and "high crane mortality due to starvation could potentially occur," according to DEFRA (2005).

The critically endangered Siberian crane faces new threats from climate change

Climate change is also cited as one possible reason for the demise of the population that once wintered in India, where droughts have become more intense and frequent and human demand for water is increasing. This is thought to be factor behind this population's dispersal away from India's Keoladeo National Park, its key wintering area, and the ensuing extirpation of this population. This highlights the negative impacts of climate change could have in moving birds out of protected areas.

21 Coniferous boreal forest.

In Europe

- Climate change has been put forward as an explanation for the decline in internationally important water bird species in the UK during the period 2001 to 2004. This includes the grey plover and dark-bellied Brent goose, whose populations peaked in the early 1990s after long periods of increase. They are now showing steady decline (JNCC 2005; Collier *et al.*, 2005).

In Asia:

- The Baikal teal is a water bird that breeds in north-east Siberia and winters in South Korea, Japan, and China. Once common, by 1990 only an estimated 50,000 remained and the bird is listed as vulnerable. As a bird that nests only in marshes it is particularly vulnerable to climate change. Lower water tables and higher rates of drought equate to reduced available habitat. Habitat loss may compromise the bird's ability to complete its migratory journey (DEFRA, 2005).

6.3.3 Coastal and seabirds

"As one of the most severe threats, one can consider rising sea levels, which might lead to severe habitat loss in coastal areas."

Böhning-Gaese and Lemoine, 2004

Nearly 20 per cent of migratory bird species (listed under the CMS) are potentially affected by loss of coastal habitat due to climate change-induced sea level rise (DEFRA, 2005). This adds an additional threat to seabirds, which have already undergone a dramatic deterioration compared to other types of birds since 1998 (Birdlife, 2004a).

Rising sea levels are expected to a have a huge impact on lowland coastal habitats around the world, and coastal bird and seabird species are likely to suffer as a result (Bairlein and Hüppop, 2004). As noted above, some parts of Europe are forecast to loose up to 100

CASE STUDY 8

Globally threatened aquatic warbler out of depth with climate change

The aquatic warbler, Europe's rarest songbird, is a globally threatened migratory bird with a known population of 13,500-21,000 singing males. Over 90 per cent of its remaining population is found in highly fragmented patches in Belarus, Ukraine and Poland; habitat destruction has eliminated western European populations, and population decline continues at a rate of 40 per cent per decade. The birds are thought to winter in sub-Saharan Africa.

Birds which nest only in marshes, like the aquatic warbler, will be particularly vulnerable to climate change. Climate change is expected to threaten the warbler by making marsh depths more variable, pushing water levels above or below the 5-12cm range preferred by breeding birds which nest in marshy zones. Drier summers will also cause declines in its insect prey. Loss of habitat and drought may further affect the bird in its African wintering grounds and during migration (DEFRA, 2005).

per cent of their wetland stock by 2080 (IPCC, 2001b; see examples below).

Sea level rise, along with storm frequency and severity will work to inundate low-lying islands, and seabird nesting colonies on them will be lost (UNEP, 2005). Increased sea level is also expected to combine with coastal squeeze to permanently inundate mudflats, and this would impact severely on wildfowl and wader species (BTO, 2002). These include mudflats of estuaries, which are important feeding sites for birds. Elevated rates of erosion will pose an additional threat, particularly in the tropics, due to more extreme weather (IPCC, 2001b).

Seabirds are showing themselves to be key early responders to climate change. This group is already being affected by well-documented prey distribution changes that are a major threat to marine ecosystems (Lanchbery, 2005; DEFRA, 2005). Plankton communities have been observed to make major shifts in response to changes in sea surface temperature; this includes shifts in distribution of up to 10° latitude, and declines in abundance to a hundredth or a thousandth of former values. Declines in krill, which form a key component of marine food webs, are considered to be of special concern. Such ecosystem changes have already affected the distribution and abundance of seabirds, such as kittiwakes, and a number of penguin species (DEFRA, 2005).

In Europe:

- Loss of coastal wetlands, important habitats for birds, will be extreme in some areas. On Europe's Atlantic coast, 0-17 per cent of wetland stock will be lost by 2080 due to climate change, on the Baltic coast 84-98 per cent, and on the Mediterranean coast 31-100 per cent (IPCC, 2001b).
- Terns, along with other sea and marshland birds found in Europe, are vulnerable to sea level rise because they nest on low-lying near shore ground. Increasing frequency of storm surge events due to climate change, particularly in the North Sea, will put further pressure on terns due to the threat of nests being washed out by storm conditions (Rehfish *et al.*, 2004a).
- UK coastal habitat supports over one quarter of the East Atlantic "flyway" populations of 10 species of wading bird. International flyway populations of over-wintering sanderling, purple sandpiper and ruddy turnstone are expected to show continuing decline to 2080 with numbers decreasing 35-60 per cent due to climate change (Rehfish *et al.*, 2004b). Furthermore, "curlew populations are expected to decline over 40 per cent in their strongholds of Shetland and Orkney, and ringed plover numbers may decline by up to 36 per cent in the Western Isles ..." Even if these birds can shift their wintering distributions to match changing climatic conditions, availability of prey and habitat changes in their tundra breeding grounds may well limit their adaptability.

6.3.4. Mountain and island birds

"Mountain ecosystems around the world, such as the Australian Wet Tropics bioregion, are very diverse, often with high levels of restricted endemism, and are therefore important areas of biodiversity. … these systems are severely threatened by climate change."

Williams *et al.*, 2003

Mountain ecosystems are hotspots[22] of biodiversity and endemism. This is because they compress a range of climatic zones and, as a rule, biodiversity, into a relatively short distance. These features also make mountain systems vulnerable to climate change. Even though the dispersal distances entailed in shifting upslope with a moving climate are relatively small, there are definite limits to upward migration.

As a result we face "the complete disappearance of specific environmental types combined with low possibility of natural dispersal to other suitable habitats," according to Williams *et al.* (2003), and as a result, "we may be facing an unprecedented loss of biodiversity in any mountain biota, an environmental catastrophe of global significance." Mountain bird species will experience this elevated threat from climate change as their suitable habitat is reduced and they cannot shift in response (DEFRA, 2005; Benning *et al.*, 2002). In warmer latitudes, tropical mountain forests are expected to dry out and be invaded or replaced by lower mountain or non-mountain species (UNEP, 2005).

Islands also tend to be biodiversity hotspots -- in fact they contain nine of the world's 12 biodiversity hotspots. This makes their biodiversity particularly vulnerable to sea-level rise. Their isolation will also limit or prevent birds and other terrestrial animals from shifting their ranges. This is of particular concern given that 23 per cent of bird species found on small islands are already threatened (IPCC, 2001b).

Thus endemic mountain and island species are vulnerable to extinction because of the limited range of suitable climate space available to them, and their limited ability to shift in response to changes. Furthermore, they may also have small populations. And although many mountain areas have isolated populations of species which may also be found elsewhere, their loss could reduce the overall genetic diversity of these species (DEFRA, 2005).

In Europe:

- Future climate change scenarios predict range contractions for birds restricted to high altitudes in the UK, such as the snow bunting and ptarmigan, and local extinction of the capercaillie by 2050 under a high level scenario of global warming (See case study 6).

In Central America:

- Bird species have already been shown to move upslope in response to climatic shifts associated with global warming (see section 4; Pounds *et al.*, 1999).

22 Biodiversity hotspots are areas with exceptional concentrations of endemic species facing extraordinary threats of habitat destruction. Twenty-five hotspots contain the sole remaining habitats for 133,149 (44 per cent) of vascular land plants and 9,732 (36 per cent) of terrestrial vertebrates (IPCC 2001b).

In Australia:

- Mountain bird species in Australia's northeastern tropical zone, such as the golden bowerbird (see section 6.2.3) are threatened by even moderate levels of warming (Hilbert *et al.*, 2004). With mid-range regional climate warming of 3.6°C, 74 per cent of Australian rainforest bird species are threatened within the next 100 years. This includes 26 species critically endangered now (Shoo *et al.*, 2005a).

6.3.5 Antarctic birds

> "...what we are going to see in the next 10, 20, 30 years is a system that is completely different from the one that exists now. Adélies [penguins] will become regionally extinct."
>
> William Fraser, Palmer Long Term Ecological Research Program (from Gross, 2005)

The current rate of Antarctic climate change implies unprecedented changes to ocean processes -- processes that affect predators at the top of the food chain, including seabirds (Croxall, 2004). The Antarctic Peninsula, the most northern and biodiverse part of that continent, is warming fastest of all locations in the southern hemisphere. The Western Antarctic Peninsula has registered temperature increases on the order of 6°C, the largest on the planet, over the past 50 years in line with IPCC predictions (IPCC 2001b). This cold, dry polar marine ecosystem is being replaced by a warm, moist maritime climate. Rising temperature and salinity trends both act to reduce sea ice production, and positive feedback is now accelerating sea ice shrinkage (Meredith and King, 2005). This is of high concern because sea ice dynamics drive Antarctic ecosystems (Gross, 2005).

Marine prey species in this region are extremely sensitive to very small increases in temperature, and population removal can result from even small ocean changes (Meredith and King, 2005). Seasonal ice cover in the Western Antarctic Peninsula is an important nursery and breeding ground for krill, which underpin the Southern Ocean food web and serve as crucial prey for many bird species (IPCC 2001b). Antarctic krill production has already dropped markedly with winter sea ice declines playing a role (Moline *et al.*, 2004). Thus the ecological implications of climate change for this area are significant.

Penguin species in the Antarctic are sensitive to climate change (Fraser and Hoffman, 2003) and recent changes in their populations, including a 33 per cent decline in Adélie penguin populations, are a reflection of regional climate change (Leemans and van Vliet, 2004). According to Croxall (2004), "Although most of the Antarctic marine avifauna is likely to be able to persist or adapt, the effects on certain high-latitude ice-associated species and on others of already unfavourable conservation status (e.g. most albatrosses, some petrels and penguins) could be serious on fairly short time scales."

CASE STUDY 9

Emperor penguin declines in the face of Antarctic warming

Highly susceptible to changes in climate: the emperor penguin

In Terre Adélie the emperor penguin population declined 50 per cent due to reduced adult survival during a late 1970s period of prolonged, abnormally warm temperatures with reduced sea ice extent (Barbraud and Weimerskirch, 2001; see figure 20). It is possible this climate anomaly is the result of global warming.

While warmer sea temperatures benefited hatching success, they also decreased food supply and reduced adult survival. The warming is linked to reduced production of krill, a staple of the penguin's diet, and this adversely affected the penguins.

Combined, these opposing effects resulted in a net decrease in breeding success, showing the emperor penguin is highly susceptible to environmental change (Barbraud and Weimerskirch, 2001; Croxall, 2004). Following this crash, population levels have stabilized at a new low level.

Figure 20

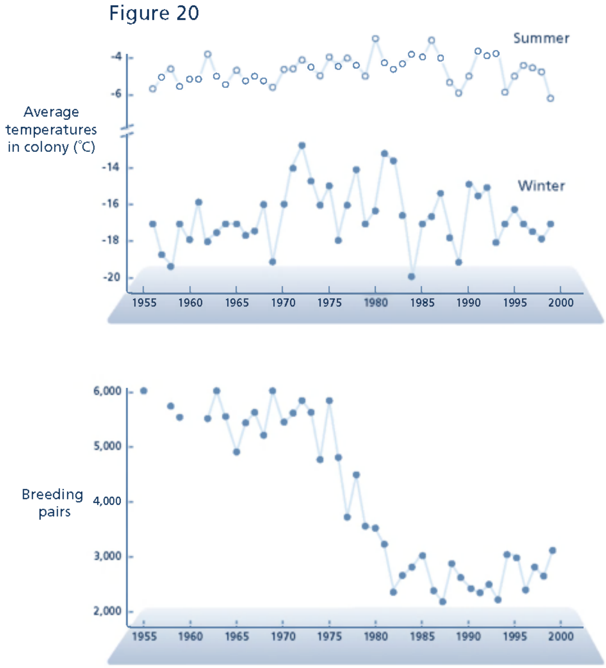


Figure 20: Warm and highly variable climate through the 1970s linked to a decline in breeding emperor penguin pairs. a = summer and winter average temperatures recorded at Dumont D'Urville meteorological station. B = number of breeding pairs of emperor penguins at Pointe Géologie Achipelago, Terre Adélie . From Barbraud and Weimerskirch, 2001.

Antarctic seabirds may also be affected by a southward shift or reduction in the extent of the Marginal Ice Zone, an area of variable, often broken ice that links open ocean to the solid ice pack. Birds breeding on the continent may be positively affected, while sub-Antarctic breeders are expected to be negatively affected. Furthermore, this zone plays a key role in reproduction and recruitment of krill, and changes to this zone may cause a shift at this level of the food chain, from krill to other species such as copepods and fish, with possibly ocean-wide consequences for seabirds and other predators (Croxall, 2004).

Shelves, shelf margins and frontal regions such as the Antarctic Polar Front are particularly important foraging areas to some species, including most penguins, and some albatross and petrel species. Shifts in nutrient availability or upwelling in these areas could have major consequences for bird species on sub-Antarctic islands, because these birds cannot easily move their breeding sites (Croxall, 2004).

In Antarctica:

- Antarctic Peninsula Adélie penguin populations have declined by 70 per cent on Anvers Island (Palmer Station) over the last 30 years due to retreating ice and increasing snowfall in response to climate warming (Fraser and Hoffman, 2003; Gross, 2005). "Adélies don't seem capable of adjusting anything about their life history... They're hard-wired to their breeding area, returning to an area year after year after year, even though conditions are deteriorating," according to William Fraser of the Palmer Long Term Ecological Research program. These climatic changes could cause the birds to become regionally extinct, according to Fraser (from Gross, 2005).
- Rising temperatures are causing salps, transparent jelly-like ocean organisms, to replace krill. Most krill-dependent predators, which include penguins, do not eat salps. Negative impacts on these predators are expected as a result (See section 4).
- Food web changes linked to warming are now considered to have caused the radical decline in rockhopper penguin numbers on sub-Antarctic Campbell Island (see section 5.2; Cunningham *et al.*, 1994).

6.3.6 Arctic birds

> "These vegetation changes, along with rising sea levels, are projected to shrink tundra area to its lowest extent in the past 21,000 years... Not only are some threatened species expected to become extinct, some currently widespread species are projected to decline sharply."
>
> ACIA, 2004

Climate change is expected to have its most pronounced influence on Arctic habitats (DEFRA, 2005) and by implication Arctic birds are expected to be among the most vulnerable.

The Arctic has warmed faster than any other region of the globe in the last century, almost two times faster than the global average. This is already contributing to profound environmental changes and the trend is set to continue, with 4-7°C of warming expected in the next 100 years according to some climate models (ACIA, 2004). Average summer sea ice extent has declined 15-20 per cent per decade over the past 30 years and overall sea ice volume was down by approximately 40 per cent on average. If this trend continues perennial sea ice will completely disappear by the end of this century (ACIA, 2004).

The Arctic has high importance for birds because approximately 15 per cent of bird species worldwide breed there. Almost all Arctic bird species are migratory, and several hundred million of them visit the Arctic each year (ACIA, 2004), including 20 million geese and waders that winter in Europe, Asia and North America (WWF, 2005a). The majority of Arctic birds breed on the tundra, the vast treeless plain lying between the Arctic icecap and the tree line to the south, characterised by permanently frozen subsoil called permafrost (DEFRA, 2005).

Climate change will cause rapid and dramatic losses in Arctic water bird breeding habitat (Birdlife, 2004a) through vegetation shifts, predicted to be most extreme for tundra areas (Zöckler and Lysencko, 2000). Overall losses of current tundra area are projected to be 40-57 per cent, with expected new tundra areas to amount to just 5 per cent (Böhning-Gaese and Lemoine, 2004).[23] This includes habitat for several globally endangered seabird species (ACIA, 2004).

Vast areas of tundra will undergo a shift to taller, denser vegetation that favours forest expansion (UNEP, 2005; ACIA 2004; IPCC, 2002). This climatically induced shift could proceed at a rate of 0.2 km/year (Birdlife, 2004a), among the world's highest rates of migration, and many species may be unable to shift sufficiently quickly to keep up (WWF, 2000). Tundra-breeding birds known as waders will not be able to adapt to bushy or tree-like terrain and so, except for a few areas gained by retreating glaciers, will be unable to gain new habitats (Zöckler, 2000). Thus important breeding and nesting areas in tundra habitats are expected to decline sharply.

As boreal forests spread north they will also overwhelm up to 60 per cent of dwarf shrub tundra, crucial breeding habitat for ravens, snow buntings, falcons, loons, sandpipers and terns (WWF, 2005a).

Climate change is predicted to have its most immediate effects on arctic seabirds (Meehan, 1998). In fact, range displacements have already begun for some seabird species (ACIA, 2004). Seabirds which forage at the margins of sea ice face a drastic reduction in conjunction with the rapid decrease in sea ice volume and extent described above. This trend is expected to continue with further climate change, pushing some seabird species toward extinction (ACIA, 2004).

23 A separate analysis shows that if all vegetation shifts with its optimal climate, tundra could decline 41-67 per cent and tundra/taiga 33-89 per cent depending on the climate model (RSPB/WWF 2003).

A further threat will come as species from the south shift their distributions northward in tandem with warming. As a result, bird species may suffer from increased competition and be displaced by invading species (ACIA, 2004).

In the Arctic:

A study of 25 Arctic water birds showed wide-ranging loss of breeding range due to changes from global warming with a doubling of CO_2 by 2070-2099 (Zöckler & Lysenko 2000). This includes:

- The globally vulnerable red-breasted goose, a bird which breeds in Arctic Europe and winters in south eastern Europe, would lose 67 per cent of its habitat with moderate warming of 1.7 °C and 99 per cent of its habitat with more extreme warming of 5°C.
- The tundra bean goose, which would lose 76 per cent of its habitat with moderate warming (1.7°C) and 93 per cent of its habitat with more extreme warming (5 °C).

The Arctic spoon-billed sandpiper, the only globally threatened sandpiper breeding in the Arctic, is one of the region's rarest breeding birds. It will lose 56 per cent of its Arctic tundra breeding area with warming of 1.7°C (moderate projection), displacing more than 1,300 of the current 2,400 breeding birds; with 5 °C of warming it will face higher risk of extinction (Zöckler and Lysenko, 2000).

Sea ice retreats will have serious negative consequences for ivory gulls, which nest on cliffs and fish through cracks in sea ice as well as scavenging the ice surface. Canadian populations of these gulls have already declined 90 per cent over the past two decades (ACIA, 2004).

Predatory Arctic birds such as snowy owls and skuas are also expected to be affected due to reductions in numbers of prey. The lemming is an important prey species which has already declined in terms of its populations cycle peaks (it undergoes cyclical population booms), and is expected to decline further with resultant stronger declines for predators; snowy owl populations are already in decline (ACIA, 2004).

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Appendix A

Common and Scientific Names of Bird Species Mentioned in This Report
(Scientific names shown in parentheses)

aquatic warbler *(Acrocephalus paludicola)*
Adélie Penguin *(Pygoscelis adeliae)*
Baikal teal *(Anas formosa)*
Baird's junco *(Junco bairdi)*
Berwick's swan *(Cygnus columbianus berwickii)*
blackcaps *(Sylvia atricapilla)*
Brunnich's guillemots *(Uria lomvia)*
Cape longclaw *(Macronyx capensis)*
Cape pygmy-owl *(Glaucidium hoskinsii)*
capercaillie *(Tetrao urogallus)*
Cassin's auklet *(Ptychoramphus aleuticus)*
checkerspot butterfly *(Euphydryas editha bayensis)*
chiffchaffs *(Phylloscopus collybita)*
collared flycatcher *(F. albicollis)*
common buzzard *(Buteo buteo)*
common guillemot *(Uria aalge)*
emperor penguin *(Aptenodytes forsteri)*
godwit *(Limosa lapponica)*
golden bowerbird *(Prionodura newtonia)*
Goldman's song sparrow *(Melospiza goldmani)*
great tit *(Parus major)*
grey heron *(Ardea cinerea)*
helmeted honeyeater *(Lichenostomus melanops cassidix)*
hoopoe *(Upapa epops)*
ivory gull *(Pagophila eburnea)*
keel-billed toucan *(Ramphastos sulfuratus)*
mallee emu-wren *(Stipiturus mallee)*
Marmora's warbler *(Sylvia sarda)*
Mexican jay *(Aphelocoma ultramarina)*
nuthatch *(Sitta europaea)*
pied flycatcher *(Ficedula hypoleuca)*
purple sandpiper *(Calidris maritima)*
red-breasted goose *(Branta ruficollis rossicus/serrirotris)*
red kite *(Milvus milvus)*
red knot *(Calidris canutus)*
resplendent quetzal *(Pharomachrus moccino)*
ringed plover *(Charadrius hiaticula)*
rockhopper penguin *(Eudyptes chrysocome)*
ruddy turnstone *(Arenaria interpres)*
sanderling *(Calidris alba)*
Scottish crossbill *(Loxia scotica)*
Siberian crane *(Grus leucogeranus)*
snow buntings *(Plectrophenax nivalis)*
snowy owl *(Bubo scandiacus)*
sooty shearwater *(Puffinus griseus)*
Spanish imperial eagle *(Aquila adalberti)*
spoon-billed sandpiper *(Eurynorhynchus pygmaeus)*
spotted flycatcher *(Muscicapa striata)*
tawny eagle *(Aquila rapax)*
tree swallows *(Tachycineta bicolor)*
tufted puffin *(Fratercula cirrhata)*
tundra bean goose *(Anser fabalis)*
western whipbird *(Psophodes nigrogularis)*
white-fronted goose *(Anser albifrons)*
whooper swan *(Cygnus cygnus)*
willow tit *(Parus montanus)*
wood warbler *(Parulidae)*

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