CHAPTER 19

Conservation consequences of climate change for birds

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19.1 Introduction

Bird species are already showing climate-related changes in the dates they migrate and breed, and in the timing of other key life-history events (Brown *et al.*, 1999; Chapters 9, 10). The distributions of many species are shifting towards the poles and higher altitudes (Pounds *et al.*, 1999; Shoo *et al.*, 2006; Niven *et al.*, 2009; Gregory *et al.*, 2009; Chapter 17). There is evidence that ecological interactions are changing, sometimes, leading to declines in population sizes (Both *et al.*, 2006). Certain bird species are also being affected by climate change through direct effects on their physiology, particularly through extreme heat and drought (Williams and Middleton, 2008). In the coming decades, many more species will probably be affected by the changing climate (Sekercioglu *et al.*, 2008; Figure 19.1). Many species that are widespread and abundant today may experience declines in population sizes, and even face extinction, while other species will increase in abundance as the climate continues to change.

In this chapter, we briefly describe several of the threats posed by climate change and outline what can be done to protect those species under threat from climate change. What can conservation biologists, conservation organizations, government agencies, and the public do to minimize the impact of climate change on bird species?

19.2 Climate change exacerbating declines in bird populations

19.2.1 Widespread declines in bird populations

Climate change is occurring at a time when the populations of many bird species, including species once thought of as common, are declining as a result of many factors on populations, such as habitat loss, fragmentation, degradation, invasive species, pollution, and over-harvesting (Butcher, 2007). Recent declines have been observed in major groups of birds, such as grassland species in North America and Europe (Butcher, 2007) and rainforest species in tropical regions (BirdLife International, 2004; Sekercioglu *et al.*, 2004; Figure 19.2), as the availability of their habitats is reduced. In some cases, the declines have been gradual, with a steady decline in numbers over decades (Butcher, 2007). In other cases, population declines have been sudden and dramatic, such as the crash in south Asian vulture populations due to the drug diclofenac (Prakash, 1999; Oaks *et al.*, 2004).

19.2.2 Effects of climate change on birds

Climate change affects the ecology and population sizes of species in many ways, including by altering ranges, interactions, and phenologies, exceeding species tolerances of temperature and other

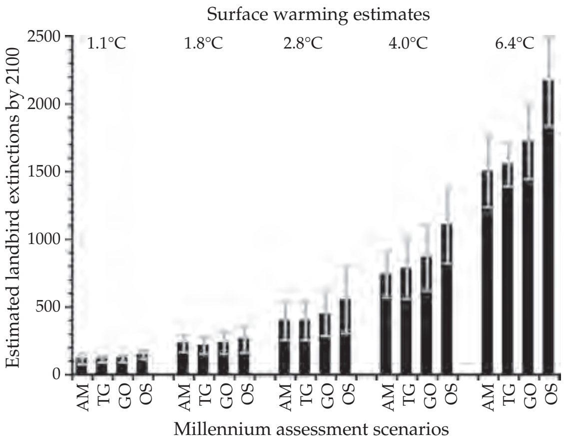

Figure 19.1 Number of world landbird species projected to be extinct by 2100 on the basis of estimates of various surface-warming estimates (IPCC, 2007), three possible shifts in lower elevational limit, and millennium assessment habitat-change scenarios (MA 2005; AM, adaptive mosaic; GO, global orchestration; OS, order from strength; TG, technogarden). Bars show the results of an intermediate amount of elevational shift, where lower limits of 50% of lowland (≤500 m) bird species are assumed to move up in response to surface warming. Error bars indicate best-case (0% move up) or worst-case (100% move up) climate-warming scenarios. See Sekercioglu *et al.* (2008) for details.

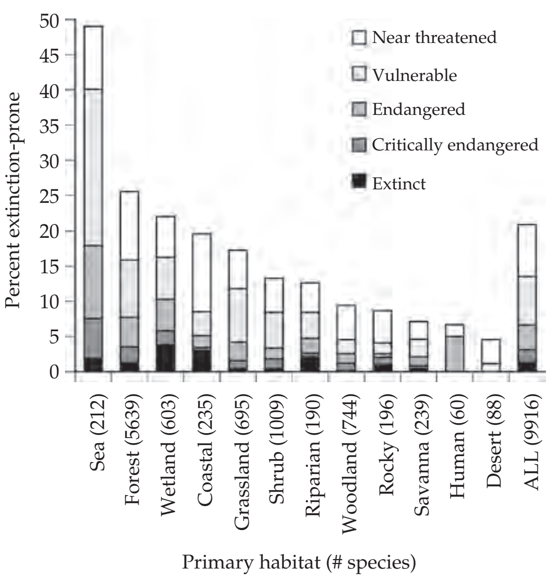

Figure 19.2 Conservation status of bird species based on primary habitat. 'Human' indicates human-dominated habitats such as farms, plantations, and towns. Number of species in each group is in parentheses. See Sekercioglu *et al.* (2004) for details.

environmental variables, and altering habitat. Importantly, climate change will interact with many other factors, sometimes in ways that are difficult or impossible to predict. For example, a bird species may not be able to track changing climate and habitat conditions by shifting its range if there is no habitat left in the appropriate location. Here we briefly describe some of the ways in which climate change affects birds. Many of these effects are discussed in greater detail elsewhere in this book.

The ranges of many bird species are already shifting towards higher latitudes and altitudes, particularly as minimum temperatures increase, allowing species to survive in new locations (Root *et al.*, 2003). For some species, shifts in climatic conditions are leading to range expansions. For other species, particularly species for which habitat is limiting or which already occur at the extreme of their temperature or drought tolerance, shifts in climate are leading to range contractions. For example, analyses of 40 years of Christmas Bird Count data in North America show that the ranges of many species, such as the spruce grouse *Falcipennis canadensis*, have shifted northwards as temperatures have warmed. Meanwhile, the ranges of other species, particularly grassland species like western meadowlark *Sturnella neglecta*, have not moved northwards, probably because of a lack of available habitat (Niven *et al.*, 2009).

These range shifts are one of the primary ways in which climate change is altering species interactions (Chapter 18). Species distributions will shift to differing degrees and at different rates, depending on each species' physiology, ability to disperse, competitors, and other, sometimes unknown, factors. As spatial and temporal assemblages of species change, species will lose historical interactions and experience novel ones. In many (but certainly not all) cases, such lost or new interactions will be detrimental to a species. For example, as a rare bird species changes its range, it may be forced to move into the range of a predator against which it has no defence, or that of another bird species that competes more effectively for limited nesting sites (Pounds *et al.*, 1999). Or the timing of breeding may become decoupled from the time when food is most abundant or available at all (Both *et al.*, 2006). In Costa Rica, the ranges of keel-billed toucans *Ramphastos sulfuratus* have recently shifted higher in elevation, into the ranges of resplendent quetzals *Pharomachrus mocinno*, on whose eggs and nestlings they can prey (Pounds *et al.*, 1999).

The phenologies of birds and the species with which birds interact are also changing at different rates (Chapter 11). Some species' phenologies are changing quickly, some more slowly, and others not at all. Many changes are unknown due to lack of research. A good example is the European pied flycatcher *Ficedula hypoleuca*, for which the timing of spring migrations has not changed because its migrations are cued by endogenous rhythms rather than temperature (Both and Visser, 2001). As a result, the timing of breeding has become mismatched with the timing of food availability in some locations, leading to declines in some populations (Both *et al.*, 2006).

Many bird species have become adapted to particular climate conditions, and as temperatures warm, they may exceed species' thermal tolerances. In some cases, species may be able to avoid these temperature increases through changes in behaviour, such as spending more time in the shade (e.g. the verdin *Auriparus flaviceps* of the southwestern USA and Mexico (Wolf and Walsberg, 1996)), burrowing in the ground, or avoiding activity during the hottest parts of the day (e.g. *Sporophila* seedeaters (Weathers, 1997)). However, in some cases, a species' behaviour may be too inflexible to allow for such changes, or refuges from warming temperatures may not be available (Deutsch *et al.*, 2008). Models indeed suggest that incidences of catastrophic heat-related mortality will increase substantially as temperatures continue to warm (McKechnie and Wolf, 2010). Such climatic intolerance may also extend to other environmental variables, such as humidity, snow cover, and cold. For example, if the humidity falls below a certain threshold, it may increase the water needs of young birds to the extent that it decreases their chance of survival. As population sizes of many bird species become limited by bottlenecks created in resources such as insects, nectar, and fruit during the dry season, increased seasonality and dry season severity linked to global climate change may substantially reduce bird populations (Williams and Middleton, 2008).

Climate change is already altering the distribution of plants, food resources, water, and other key aspects of habitats (IPCC, 2007). For example, many bird species are restricted to specific habitat types, such as grasslands, deciduous forest, or evergreen forest. If the range of a particular habitat type begins to contract because of changing climatic conditions (or any other cause), then the bird species will also decline. Many models of changes in bird abundances and distributions are based on this simple but critical association between birds and habitat (Benning *et al.*, 2002; Rodenhouse *et al.*, 2008). For example, as sea levels rise because of warming temperatures, birds that rely on coastal and estuarine habitats will face dramatic changes in habitat availability (Galbraith *et al.*, 2002; Hughes, 2004). In most parts of the developed world, the availability of coastal habitat is already severely limited because of development. Sea level rise will inundate much of the existing habitat for some of these species, potentially leaving them with little or no remaining habitat. They may not be able to migrate to higher ground because of the presence of houses, cities, roads, sea walls, and other structures associated with human occupation. For such species, extinction is a real and immediate threat.

19.2.3 Interactions with other global changes

As species ranges shift, will appropriate habitats be available to them in new locations, or have changes in land use created too many barriers? This is a major question for many species, such as the coastal birds mentioned above. By and large, birds are relatively mobile and able to move to new locations as conditions change. However, the plants and animals on which they depend for habitat and food may not be able to move, particularly in a highly fragmented landscape. Relatively immobile birds will face these same barriers. Models combining a variety of climate change and habitat loss scenarios suggest that sedentary bird species are five times more likely to go extinct from range shifts forced by climate change than are migratory species (Sekercioglu *et al.*, 2008).

Invasive species have already altered the dynamics of many bird populations (Chapter 18). As the climate changes and human transportation and development continue, invasive species are likely to become more common and occupy a wider range of habitats (Smith *et al.*, 2000). One can expect that the impacts of these invasive species on bird populations will expand as well. These invasive species can harm bird populations directly, as when rats feed on birds and eat their eggs. Invasive species may also affect birds indirectly, as when invasive plant species, which may spread faster as a result of climate change (Dukes and Mooney, 1999), alter a habitat so completely that the food plants needed by bird species are no longer available.

The distributions of many pests and diseases are spreading as temperatures warm, allowing them to infect species that previously lived in areas outside their climatic tolerance (Traill *et al.*, 2009; Chapter 15). Exposure to new pests and diseases could lead to severe declines in naïve populations. For example, mosquito species are extending their ranges to higher elevations in many tropical montane areas (Kilpatrick, 2006). Certain of these species are vectors of diseases that affect both humans and birds, such as malaria or West Nile virus (Benning *et al.*, 2002). At many locations in the USA, outbreaks of insects, such as mountain pine beetles and spruce budworms, associated with warming temperatures, are degrading many forest ecosystems (Logan *et al.*, 2003). Bird species that depend on these forests for most or all of their ecological requirements may face population declines.

19.3 Projections for the future

19.3.1 Models of future species distributions

Predictions of changes in future ranges are fraught with difficulties and problems (Beale *et al.*, 2008; Chapter 8). Many of the processes and biotic interactions that regulate species distribution dynamics are little known, and excluding them may result in erroneous models of future species distributions (Preston *et al.*, 2008; Vallecillo *et al.*, 2009). Small sample sizes of distribution data can reduce model accuracy (Wisz *et al.*, 2008), and the ability of some species to adapt to climate change is rarely considered in models (Schwager *et al.*, 2008). Additional data on the distributions, demography, habitat requirements, and ecological interactions of species could substantially improve these models, but acquiring such data can be quite labour intensive. Nevertheless, new remote-sensing products are expanding the spatial extent of

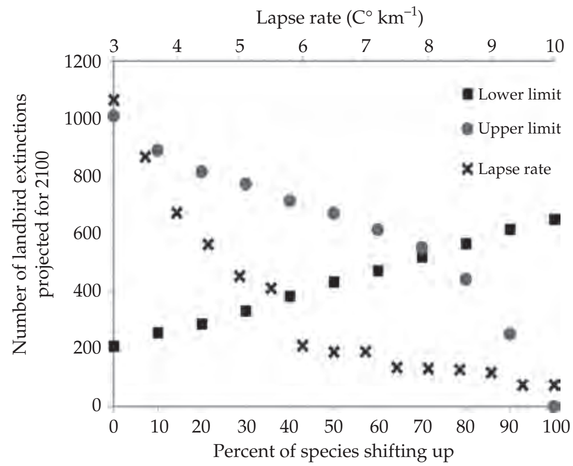

Figure 19.3 Sensitivity analyses of temperature lapse rates and lower- and upper-limit elevational range shifts on the numbers of projected bird extinctions for 2100. Lapse rate is the rate of air temperature decrease with increasing elevation. See Sekercioglu *et al.* (2008) for details.

available habitat and climate data, which can be combined with new modelling approaches to improve the accuracy of distribution models (Buermann *et al.*, 2008; Wisz *et al.*, 2008). Additionally, climate envelope models applied to past data have predicted actual changes observed in bird species' population trends with reasonable accuracy, although much of the variation in actual population trends was not explained by the models (Green *et al.*, 2008). Furthermore, modelling bird species' future distributions can demonstrate the impact of different climate change scenarios on the magnitude of extinctions resulting from distribution shifts (Figure 19.1), show the sensitivity of expected extinctions to model parameters (Figure 19.3) like surface warming or lapse rate (the rate of air temperature decrease with increasing elevation), reveal areas where more data are needed (e.g. tropical elevational shifts), and highlight groups that are currently considered safe but are likely to face extinction due to climate change (Sekercioglu *et al.*, 2008). Rapidly growing interest in modelling species distributions is improving model accuracy and sophistication, which is important because these models' predictions are critical in prioritizing the taxa, habitats, regions, and problems that require the urgent attention of conservationists.

19.3.2 Predictions of future species declines and extinctions

Despite remaining challenges in modelling future ranges, there is a growing consensus that climate change will result in an increase in threatened and extinct species, in numbers likely to grow non-linearly with increasing surface temperatures (Sekercioglu *et al.*, 2008) (Figure 19.1). As described above, species ranges are expected to shift towards the poles and higher elevations (Preston *et al.*, 2008; Chapter 17); the timing of phenological events will change, possibly leading to temporal mismatches (Both *et al.*, 2006; Chapter 11); distances between breeding and non-breeding ranges may increase for migratory species (Doswald *et al.*, 2009; Chapter 9); and sedentary and range-restricted species are expected to have major population reductions due to lower mobility, more specialized habitat requirements, and less or no overlap between current and future ranges options (Sekercioglu *et al.*, 2008; Doswald *et al.*, 2009). A recent study that estimated future extinctions of land bird species due to climate change found that most species projected to become threatened or go extinct due to climate change by 2100 are not currently considered threatened or near threatened on the International Union for Conservation of Nature (IUCN) Red List (Sekercioglu *et al.*, 2008). The main reason for this is that most species are currently considered to be threatened by habitat loss or exploitation, which is linked to human activities concentrated in the lowlands and relatively flat terrain. On the other hand, climate change is likely to threaten many species endemic to tropical mountains that have less human presence because of their steep topography. This complementarity between climate change, habitat loss, and exploitation may be the biggest conservation challenge of the 21st century.

19.4 What can be done to enhance bird conservation in the face of climate change?

19.4.1 Identifying vulnerable species and habitats

A variety of models predict that many bird species will have difficulty adjusting to climate change and will gradually go extinct within their current range. Given this fact, one of the most pressing questions facing managers and conservation biologists is: which bird species are most vulnerable to changes in climate? Many traits can contribute to a species' vulnerability to climate change: dispersal ability (Sekercioglu *et al.*, 2008), tolerance of only a narrow set of temperature or precipitation regimes (Deutsch *et al.*, 2008), dependence on a particular disturbance regime (such as fire) likely to be altered by climate change, dependence on ice- or snow-covered habitats (Jenouvrier *et al.*, 2009), a high degree of habitat specificity (Hilbert *et al.*, 2004), reliance on specialist inter-specific interactions (e.g. for food or habitat), low genetic variation, and a lack of phenological response to climate change (Both and Visser, 2001).

Groups of investigators are beginning to develop indices of vulnerability to climate change, but the data necessary to generate meaningful conclusions are often lacking. Studies of individual species will need to measure these and other traits to predict how species will respond to climate change. Because some of these traits are difficult or take a long time to measure, however, indicators may be able to provide 'quick and dirty' estimates of vulnerability. For example, current population size is often used as an indicator of vulnerability to many kinds of threats. Populations consisting of relatively few individuals may be wiped out by a single disturbance event and tend to have lower genetic variation, limiting their ability to evolve in the face of changing conditions. Phylogenetic relationships may also provide insights. Species often share traits with other species to which they are closely related. If a particular species has a trait that makes it vulnerable to climate change, it is likely that closely related species might also be vulnerable. This concept has recently been successfully applied to plants (Willis *et al.*, 2008), but has yet to be tested in birds.

19.4.2 Inclusion of climate change in IUCN and other species' classification systems and management planning exercises

The IUCN has developed a system for classifying the degree of endangerment of species (IUCN, 2009). The current system relies primarily on the numbers of individuals of a species presently alive, predictions of future population sizes, and the area that a species occupies. Immediate threats to its habitat can also be considered. In addition to the threats posed by human activity, such as over-harvesting and habitat destruction, climate change needs more consideration as an important threat, leading to species endangerment. Future climate change could result in a direct decrease in the number and size of populations for a species, and indirectly affect a species through the loss of habitat. A recent analysis of the 2008 IUCN Red List of Threatened Species (www.redlist.org) found that 35% of the World's 9856 extant bird species have traits that make them susceptible to climate change (Vié *et al.*, 2009). A new initiative is underway to examine how the IUCN Red List criteria can be used to identify species most at risk from climate change (Vié *et al.*, 2009), and a classification of 'potentially threatened by climate change' should be considered for the Red List.

19.4.3 Support for species in their current range

Many species are declining within their current ranges due to the range of human activities discussed above: habitat destruction, habitat fragmentation, pollution, invasive species, disease, and others. Climate change will place an additional burden on many species of conservation concern. Although we cannot stop climate change in the short term—we are already committed to substantial changes in climate regardless of mitigation strategies currently in place and being proposed—we can manage for many of the other stresses that species face, maximizing the ability of species to adapt to changing climatic conditions and associated changes in habitat (Glick *et al.*, 2001; Heller and Zavaleta, 2009; Mawdsley *et al.*, 2009). Many of the strategies that already exist for endangered and other bird species will work to a greater or lesser extent for species threatened by climate change. The conservation tools will remain the same, but the way they are applied will change.

The most effective strategy for preventing the extinction of species is almost always to protect and manage them within their existing ranges. This strategy is more effective than moving them elsewhere because it is only within the present range of species that we can be certain that all of the ecological and environmental requirements for a species are being met. For any endangered species, the first strategy is to protect as much as possible of the habitat that it occupies within its current range, preferably through protected areas, such as national parks and other legal entities, or in private conservation networks.

For many species, particularly in the tropics, detailed information on their ecology is not readily available. Some species ranges are only known approximately, and some of the most threatened and specialized species do not occur in most places they are thought to occur (Jetz *et al.*, 2008). The food and nesting requirements, species interactions, and patterns of migration and habitat use are poorly documented or completely unknown for even more species. Thus, documenting species' ranges, their habitat associations, and other aspects of their ecology is critical for the application of conservation strategies to the appropriate locations. For example, if a species needs small, open habitats in which to find food or to build its nests, then periodic disturbances, such as fires or selective logging, may be used to create and maintain such habitats in otherwise forested landscapes. Or a species may have very specific requirements for nesting and feeding. Without ecological research and population monitoring, some species may still disappear from seemingly intact habitat.

Whenever possible, management should be combined with monitoring to measure the effectiveness of the management treatments in an adaptive management context (Reever Morghan *et al.*, 2009). Adaptive management practices are particularly important in light of climate change. Because the effects of climate change and its interactions with other global changes are difficult to predict, managers will need to monitor key variables and periodically assess the efficacy of management practices. If it is determined that management activities are not effective in stabilizing or increasing bird populations, then the management plan can be adjusted.

19.4.4 Habitat restoration

In addition to managing populations within their current ranges, land managers can assist bird populations by restoring degraded habitat that is not presently occupied by a target species. Habitat that has been damaged by human activity may be of little value for in situ conservation or ecosystem services. Consequently, conservation biologists may have an opportunity to use these lands for creating new habitat for endangered bird species. For example, if riparian habitat is being eliminated for a bird species in one location, restoring riparian habitat in a new location or using restoration to expand an existing patch of habitat may be a strategy worth considering (Kus, 1998). This new forest might eventually be colonized by the target bird species, or the bird might be released as part of a carefully planned conservation programme.

Islands have particular value in such restoration efforts where the effects of human activities and invasive species can be controlled. For example, if hunting is causing the decline of a species throughout its range, managers can sometimes control hunting on islands with limited access (Machado *et al.*, 2009). Also, the introduction of invasive species can be carefully regulated and controlled on islands. It is possible to eradicate invasive species, such as rats and feral cats, that depredate or otherwise affect birds from some islands, as has been done in New Zealand and other locations (Towns and Broome, 2003). If a species, whether endemic to islands or larger landmasses, is declining throughout its range because of human activities and climate change, these species could be translocated to islands where the species could survive, even if the species did not naturally occur there (Armstrong *et al.*, 2002; Miskelly *et al.*, 2009). Nevertheless, managed translocations are a last resort action that requires extreme care and prior research before any animal is moved (Hannah, 2008; Mueller and Hellmann, 2008). The issues involved in such deliberate introduction of species beyond their normal range are discussed in more detail in a later section.

19.4.5 Establishing new conservation areas or corridors for species

A challenge for government officials, conservation biologists, and members of conservation organizations is to identify locations that are not presently occupied by endangered bird species but might be suitable for them in the future, based on climate change predictions. The challenge is to expand the present system of protected areas to include such places in cases where they are not already protected (Hole *et al.*, 2009). Studies are beginning to use downscaled models of climate change and other landscape characteristics to identify habitats that are likely to be important to particular bird species in the future (Preston *et al.*, 2008; Rodenhouse *et al.*, 2008). Currently, there is a high degree of uncertainty in many models, but this is an active area of research and improvements are occurring rapidly.

For birds that are long-distance migrants, their flyways are already known to a greater or lesser extent. Many of the most important stopover points along the way are protected, as it is recognized that birds need places to rest and to feed as they carry out their annual migrations. However, bird migrations are expected to get longer (Doswald *et al.*, 2009), or shorter (Chapter 9), and many bird species will gradually extend their ranges further from the equator as the climate warms. Additional protected areas will need to be created to accommodate changes in their breeding sites and migration pathways. For example, if a rare species of bird extends its range further north in Canada to an island that it previously did not occupy, then habitat protection might need to extend to its new range.

In many cases, species will simply expand their ranges by occupying habitat that is adjacent to their present ranges. Many montane bird species will extend their ranges upwards on the slopes to cooler, wetter, and more humid places, depending on their physiological tolerances and habitat requirements (Shoo *et al.*, 2006). For example, a forest patch further upslope that was formerly too cold for a species may now have the ideal temperature (Pounds *et al.*, 1999). Or a forest bird species might gradually move upslope as its forest habitat also moves upslope, tracking a changing climate (Shoo *et al.*, 2006). Conservation biologists can facilitate bird conservation efforts by ensuring that individual mountains and mountain chains with endangered birds are protected, including the entire gradient from the lowlands to the top of the mountains. In many cases, such mountains are already protected due to their widely recognized role in watershed protection. Their importance in providing protection to bird species threatened with climate change provides a further argument for the protection of montane forests covering wide elevational ranges.

19.4.6 Managed translocation of species

As climate changes, many bird species will be able to extend their range to places both near and far from their existing ranges and occupy newly suitable territories (Doswald *et al.*, 2009). However, this may not be the case for certain species for a variety of reasons. First of all, certain bird species, such as ratites, some rails and ducks, and the kakapo (*Strigops habroptila*), have lost the ability to fly. Other species are weak fliers, incapable of migrating long distances (Sekercioglu, 2007) (Figure 19.4). These species tend not to leave their home ranges to seek new places to occupy and may not be able to adjust their ranges except by slow overland migration. Second, species may not be able to find new habitats with appropriate climate conditions. For example, penguins can swim long distances but may still be unable to locate those rare locations suitable for establishing new colonies. Third, for species that already have small populations, the number of individuals dispersing long distances is small and may not be sufficient for a founder population. Bird species found in tropical mountains are especially vulnerable because they may be unable to cross the hot, bright open lowlands, often dominated by farming and other human activities, that separate mountains (Ghalambor *et al.*, 2006; Sekercioglu *et al.*, 2008).

For species that are declining due to climate change, one possible solution is to move groups of individuals to new locations where new populations can be established (Hannah, 2008). Such movements of species have been called assisted migrations, managed migrations, or managed translocations. New locations for such managed translocations must be studied carefully in advance to make sure that the location is adequate and that the species is not likely to have harmful ecological impacts on its new habitat (Mueller and Hellmann, 2008). Historical case studies can also inform managed translocations. For hundreds of years, birds have been moved to new places by human activity, as in cases of establishing game species, translocating species familiar to European settlers, and the conservation of threatened species. Once the birds are released into the new site, the newly established populations must be monitored for their size, the health of the individuals, and reproductive success.

One concern of using managed migrations is that an introduced species may rapidly increase and place another endangered species or even an entire ecosystem at risk (Mueller and Hellmann, 2008). Such concerns must be considered very carefully before moving a new species by some tens or even hundreds of kilometres within the same biogeographical area. The possibility of harm could be reduced by selecting a site where there are no other endangered or directly competing species. However, when translocating a rare species, a significant concern is the possibility that the new population will fail to establish and that this rare species will continue to decline towards extinction.

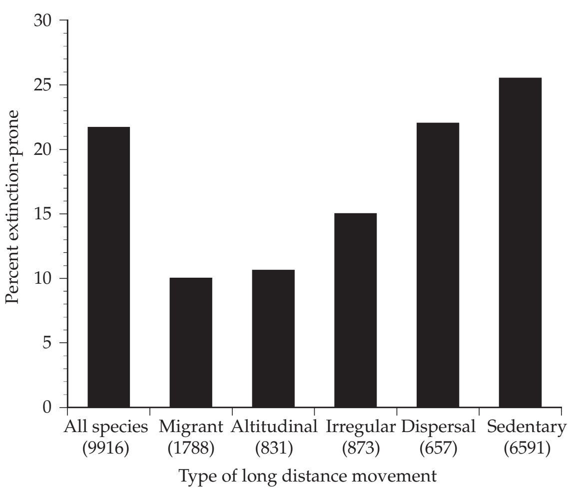

Figure 19.4 Extinction risk as a function of long-distance movement. Bird species with regular long-distance movements are less extinction prone (threatened, near threatened, or extinct) than sedentary birds or those that only undertake long-distance post-fledging dispersal. The number of species known to undertake that type of movement is in parentheses. See Sekercioglu (2007) for details.

19.5 Case studies

Here we present a series of case studies describing species that are already being impacted by changing climatic conditions or are likely to be impacted in the future. These cases highlight the variety of ways in which climate change can affect species directly and through interactions with other factors. The cases also demonstrate many of the challenges that conservation biologists and others face as they manage species and ecosystems in a rapidly changing climate.

19.5.1 Murrelets: cold-loving seabirds in a warming ocean

The globally and federally threatened marbled murrelet *Brachyramphus marmoratus* has higher reproductive success and productivity when lower water temperatures lead to increased fish availability (Becker *et al.*, 2007). This suggests that warming sea temperatures can lead to future population declines. A closely related species, the Kittlitz's murrelet *Brachyramphus brevirostris* already seems to be declining because of climate change (Kuletz *et al.*, 2003). Seventy per cent of the world population of marbled murrelets occurs in Alaska, where the species has declined >80–90% in the past 15 years, with a change in status from Least Concern to Critically Endangered between 2000 and 2004 assessments (BirdLife International, 2009). Sizeable populations occur in fjords with stable or increasing glaciers, whereas populations are disappearing from fjords where glaciers are declining or are not present (Kuletz *et al.*, 2003). As many of Alaska's glaciers recede in response to climate change, the populations of Kittlitz's murrelets and other pagophilic species may also experience further declines. Because of the grave threats to their populations, murrelet nesting areas must be carefully protected; such actions involve minimizing human activity, such as camping and logging activity in nesting areas. Consideration should be given to managing fisheries in murrelet feeding areas to increase food availability.

19.5.2 Bowerbirds on tropical mountains

Some of the species most sensitive to climate change are expected to be species restricted to mountaintops. This is particularly true in the tropics where hundreds of montane endemic bird species are sedentary and are unable to cross the hot lowlands (Janzen, 1967). One of the best examples is the golden bowerbird *Prionodura newtonia*, which is limited to forests between 700–1500 m in the Wet Tropics World Heritage Area of northeastern Australia. Hilbert *et al.* (2004) modelled present and future suitable habitat for this species using a generalized linear model. Assuming a 10% decline in precipitation due to climate change, the global range for this species will decline substantially with surface warming and may disappear entirely if warming above 3 °C takes place (Hilbert *et al.*, 2004). Similar range reductions are expected for other tropical montane species in the region (Williams *et al.*, 2003). Managers should consider creating captive bird colonies of such species and eventually relocating them to other suitable areas within the same biogeographical region elsewhere in Australia.

19.5.3 Emperor penguins with less sea ice

In the public imagination, no group of birds is as linked to ice and cold as penguins. Although the Galapagos penguin actually lives on the equator, this and other species are all associated with cold water and may decline in response as sea temperatures warm. The most cold-adapted bird species of all, the emperor penguin *Aptenodytes forsteri* of Antarctica, is expected to suffer some of the most severe climate-related declines of any bird species (Jenouvrier *et al.*, 2009). These birds use sea ice for feeding, breeding, and moulting. Consequently, anticipated declines in sea ice extent are expected to reduce the large Terre Adelie population by over 90% by 2100 (Jenouvrier *et al.*, 2009). As emperor penguins breed slowly and have not yet adjusted their breeding dates in response to changing climatic conditions (Barbraud and Weimerskirch, 2001), they are unlikely to adapt to the rapid changes currently in progress. In fact, the northernmost emperor penguin population is on the brink of extinction (SCAR, 2003) and this iconic species of the ice is likely to experience a large range reduction (Jenouvrier *et al.*, 2009). For such species, extinction in the wild is a real possibility, and its future may require continued existence in carefully managed captive colonies that maintain many of the environmental features of its natural habitat.

19.5.4 Hawaiian honeycreepers face multiple threats

The Hawaiian honeycreepers (Drepanidae) illustrate the varied effects of climate change on island birds. This family is an excellent example of adaptive radiation that has given rise to dozens of species of varying sizes, bill shapes, and feeding habits. However, a combination of habitat loss, introduced predators, and avian malaria (transmitted by introduced mosquitoes) has driven many honeycreepers extinct, and they have become the 'poster birds' of island extinctions (Pimm *et al.*, 1994). Climate change is presenting yet another threat to these birds, as it is expected to lead to a reduction in these birds' preferred high-elevation forest habitat while pushing malaria-carrying mosquitoes to higher elevations (Benning *et al.*, 2002). This double-edged sword of climate change is expected to lead to further extinctions of Hawaiian honeycreepers (Benning *et al.*, 2002). As the climate warms, these populations will need to be intensely managed to maintain their populations. Such efforts might involve restoring degraded areas, planted preferred food plants, and removing introduced predators.

19.5.5 Waterfowl with less water

Due to their link to wetlands, rivers, and other water bodies, waterfowl will be particularly impacted by increased temperatures, reduced rainfall, and increased incidence of drought conditions. Many waterfowl gather in large congregations, which means that the drying of a particularly important wetland can have a disproportionately negative impact. This tendency of waterfowl to gather in large groups also makes them susceptible to disease transmission (Benning *et al.*, 2002). Because many waterfowl are long-distance migrants, they can also play a role in spreading disease globally, as is sometimes suspected for H5N1-type avian influenza. Consequently, the expected increase in disease prevalence due to climate change can affect many waterfowl species negatively, especially when combined with other impacts like hunting. Traill *et al.* (2009) showed that increased disease prevalence due to climate change, when combined with hunting, will lead to a steady decline in the future population of magpie goose *Anseranas semipalmata* in Australia. Similar synergies may also take place in other waterfowl susceptible to disease and hunting, but research on this front is almost non-existent. An urgent priority is to model the effects of climate change on wetlands that are critical to rare and endangered waterfowl. Ramsar sites would be particularly appropriate for such investigations. In such sites, the maintenance of water levels should be a high priority; a certain minimum level of water is necessary to protect the wetlands and the birds that live there. The amount of water needed for such places will probably grow as the temperatures rise and evaporation from such areas increases.

19.5.6 What happens when ecological linkages are broken?

Climate change presents unique challenges to migratory species. Even though long-distance migrant bird species are less likely to go extinct from climate change due to their increased mobility and tolerance to a wider range of conditions (Sekercioglu, 2007; Sekercioglu *et al.*, 2008), these birds also have to deal with more climatic zones, are highly susceptible to extreme weather events during their migrations, and are more likely to suffer from phenological shifts than are sedentary species. The synchrony of maximal food abundance with the breeding period is particularly critical. Earlier peaking of insect prey populations in The Netherlands due to climate change has led to the mistiming of peak food abundance for migratory pied flycatchers. In turn, this has led to declines in abundance of up to 90% in some populations over the past two decades (Both *et al.*, 2006). Mistiming of critical events in the avian life cycle is likely to increase as a result of climate change, and more research is needed on the role of climate-induced phenological changes on avian population declines (Møller *et al.*, 2008). It is critical to determine whether the example of the pied flycatcher is an exceptional case, unlike other species of Europe or other continents, or is the pied flycatcher the first documented example of a phenomenon that affects many other migratory species? For the pied flycatcher itself, what can be done? Is the species committed to extinction because of an ecological mismatch? Perhaps, the species will naturally migrate to regions further north where its arrival will have a better fit with local food abundance, or populations could evolve earlier migration times (Jonzén *et al.*, 2006).

19.6 Priorities for future research and management actions

The rapidity, scale, and breadth of the impacts of climate change require that it be a major component of plans for the management of species and ecosystems. However, despite the recent surge of research on the impacts of climate change on birds and other species, our understanding of these impacts and how to manage for them is woefully limited. The priorities for research can be divided in to four basic categories: (1) basic ecology, (2) impacts of climate change, (3) future habitats, and (4) management practices.

19.6.1 The basic ecology of species

We still understand very little about the basic ecology, for example the range, habitat requirements, key interactions, and climate sensitivity, of most species. This lack of understanding can severely handicap plans to create effective management of target species, particularly those that are threatened or endangered. The importance of this type of basic research is easily overlooked when evaluating all of the unknown factors related to conservation in a changing climate, but it provides knowledge that is often crucial to successful management plans.

19.6.2 Impacts of climate change

Most climate change research in ecology to date has been focused on the impacts of climate change (Hughes, 2000; Peñuelas and Filella, 2001; Walther *et al.*, 2002), and our understanding has increased rapidly in recent years (IPCC, 2007). Hundreds of studies have documented how species are already responding to climate change. However, the uncertainty of future changes in climate and the complexity of species responses make it difficult to accurately predict how species are likely to respond to future climate change. Much new research is focusing on improving forecasts of climate change, reducing their uncertainty and downscaling them to ecologically meaningful scales (Vrac *et al.*, 2007; Cayan *et al.*, 2008). Additional research is exploring the complex factors that contribute to species responses to climate change, incorporating these factors into models that more accurately predict future responses (Ibáñez *et al.*, 2006; Morin *et al.*, 2007). Some investigators are using these factors to identify groups of species that are particularly responsive or unresponsive to climate change. For example, the migration times of long-distance migrants tend not to change as temperatures warm, whereas the migration times of short-distance migrants change relatively rapidly (Butler, 2003; Miller-Rushing *et al.*, 2008; Chapter 9). The potential to use these methods to identify indicator species that might be used as proxies for difficult-to-observe species, as many rare species are, deserves further study.

19.6.3 Future habitats

A primary tool of conservation organizations is land acquisition and protection. As species ranges shift in response to changing conditions, identifying the appropriate parcels of land necessary to preserve a species becomes problematic. Groups are beginning to use models that combine information on climate, vegetation, geology, fire, and other factors to identify areas where species are likely to occur in the future (Scheiter and Higgins, 2009; Vallecillo *et al.*, 2009). Currently, these models contain a high level of uncertainty. It is important that work on these models continues to reduce uncertainty and to identify areas that are likely to be appropriate to protect in a range of climate scenarios.

19.6.4 Management practices

Conservation biologists and natural resource managers cannot wait for better science before beginning to implement management practices aimed at mitigating the effects of climate change on particular species or ecosystems. In many areas, these projects are already underway, providing examples that managers can follow in other locations, although work on most projects has not yet been published. Given the uncertainty of climate change and its impacts, however, we emphasize that management practices should use an adaptive management framework whenever possible—identifying management questions and goals, implementing management practices, testing the effectiveness of the practices, and re-evaluating and revising the practices (Reever Morghan *et al.*, 2009). The critical need for this type of applied research has been widely recognized, and in fact, the US Department of Interior is implementing a series of landscape conservation cooperatives to provide a formal structure for testing management practices on a large scale (Salazar, 2009).

19.7 Conclusions: active vs. passive conservation

Bird species are already responding to rapid changes in climate, altering distributions, phenology, and population dynamics (Crick, 2004; this volume). Because of these changes and interactions between climate change and other global changes (e.g. habitat loss, fragmentation, invasive species, and pollution), many bird species that are currently common will probably become endangered, and many species that are already endangered may face extinction (Sekercioglu *et al.*, 2008) (Figure 19.1). Other species will increase in abundance as conditions become more favourable for them. The rapidity, scale, and impacts of climate change require that conservation biologists adjust the practices used to manage species in light of climate change. However, in most the management tools will remain largely the same, but the way they are applied will change (Glick *et al.*, 2001; Heller and Zavaleta, 2009; Mawdsley *et al.*, 2009). Essential steps to manage the impacts of climate change include (1) identifying and monitoring species most at risk from climate change, (2) managing existing populations and the habitats in which they live to maintain these populations, (3) acquiring new protected areas in places where ecological communities are expected to shift in response to climate change, (4) restoring degraded habitats of species at risk, and (5) transporting endangered bird species to suitable locations where they can establish new populations. Because climate change may cause existing habitats to become unsuitable for many species, conservation strategies must anticipate where bird species ranges will shift in the coming decades. Additionally, because the effects of climate change and its interactions with other global changes are difficult to predict, adaptive management strategies—in which the ability of management strategies to achieve their goals is constantly reassessed—will become increasingly important.

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