

CHAPTER 24

Modern Climate Change and Birds

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Across the globe, climate influences the distribution and abundance of bird species and their habitats ([chapters 18, 22](#)). Although birds have numerous adaptations that allow them to accommodate changes in weather and climate, concern is mounting that human-induced climate change represents a unique and growing conservation threat. The most recent assessment of the Intergovernmental Panel on Climate Change (IPCC)—a global collaboration of scientists tasked with evaluating the scientific information on human-induced climate change—warns that the warming of the Earth’s atmosphere and oceans is now unequivocal, because of continued increases in concentrations of greenhouse gases. These global changes in the climate system have resulted in altered water cycles, rising sea levels, diminishing snow and ice cover, and a higher frequency of extreme weather events (IPCC 2013). Most worrisome is that the rates of many of these observed changes are unprecedented over decades to millennia. In this chapter, we present an overview of some of the major changes in the Earth’s climate and discuss the implications of these changes for bird behavior, phenology, population dynamics, distributions, and conservation.

A WARMING WORLD

Each of the last three decades (1980s, 1990s, and 2000s) has been successively warmer at the Earth’s surface than any preceding decade since 1850. From 1880 to 2012, land and ocean surface temperatures have shown a warming trend of 0.85°C (Hartmann et al. 2013) ([fig. 24.1](#)). This global trend has resulted in the Earth being, on average, 0.78°C warmer in the early twenty-first century compared with the late nineteenth century. For many bird

populations, this shift in the global climate reflects even more alarming changes in temperature at regional scales. For example, birds inhabiting and breeding in the more northerly latitudes are considered at greater risk since many of these regions have been experiencing some of the more rapid increases in temperature (fig. 24.1). Across the Northern Hemisphere, the period of 1983 to 2012 was likely the warmest 30-year period of the last 1,400 years (IPCC 2013), and arctic temperatures have risen almost twice as quickly over the past 100 years compared with global temperature trends (Christensen et al. 2013). The rate of temperature change in relation to geographic gradients (referred to as **climate velocity**, °C/km) has been faster across land compared with oceans and fastest in low elevation, open habitats such as grasslands, heathlands, and wetlands (Loarie et al. 2009, Burrows et al. 2011). Although changes in the global climate systems occur as a result of natural phenomena (e.g., sun cycles, changes in the earth's orbit), it is increasingly clear that recent warming is driven by an increase in fossil fuel emissions and rising levels of CO² in the atmosphere. Over the next 100 years, the IPCC predicts that global surface temperature increase is likely to exceed 1.5°C under most future models and Representative Concentration Pathways (see the box on page 756). Under RCP 8.5, the Earth will experience substantial warming over all terrestrial regions by the end of the twenty-first century. The greatest warming will occur in northerly regions, including more than 4°C above current climate conditions. By the end of the twenty-first century, warming is predicted to exceed 4°C over most land areas, with much of northern North America and northern Eurasia exceeding 6°C (Diffenbaugh and Field 2013) (fig. 24.2). The results of these projections depict a sobering reality: the observed warming over the past 100 years pales in comparison with future changes.

COMPLEX CHANGES IN PRECIPITATION

Global temperatures have not been the only aspect of the Earth's climate system to change. Changes in the global water cycle have resulted in significant, yet complicated, trends in precipitation. Since the mid-twentieth century, a general pattern has emerged of increasing annual precipitation in many parts of the world (IPCC 2013). Up until the early 2000s, tropical regions were the exception to this rule, and parts of South America and Africa showed increased drying and drought conditions in many areas.

However, increasing precipitation in the 2000s appeared to reverse the drying trend, especially in South America. Drying in other regions, such as Western Africa and East Asia, have continued unabated and exacerbated the contrast between wet and arid regions of the world. This poses a significant problem for birds occupying arid regions that have life histories that are critically in line with pulses in precipitation and resources. In the future, substantial changes in annual precipitation are expected for many regions of the world (Diffenbaugh and Field 2013), including increases over the high northern latitudes and decreases over the Mediterranean region and regions of southwestern South America, Africa, and Australia ([fig. 24.2](#)). Under most scenarios, it appears that future climate change will result in overall wetter conditions, but these trends are complex and many regions are expected to demonstrate significant decreases in annual precipitation.

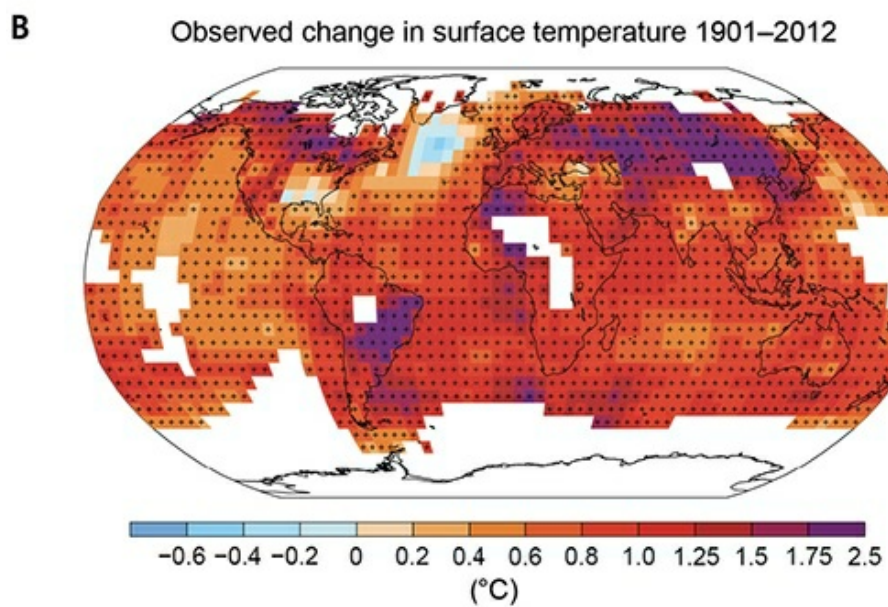
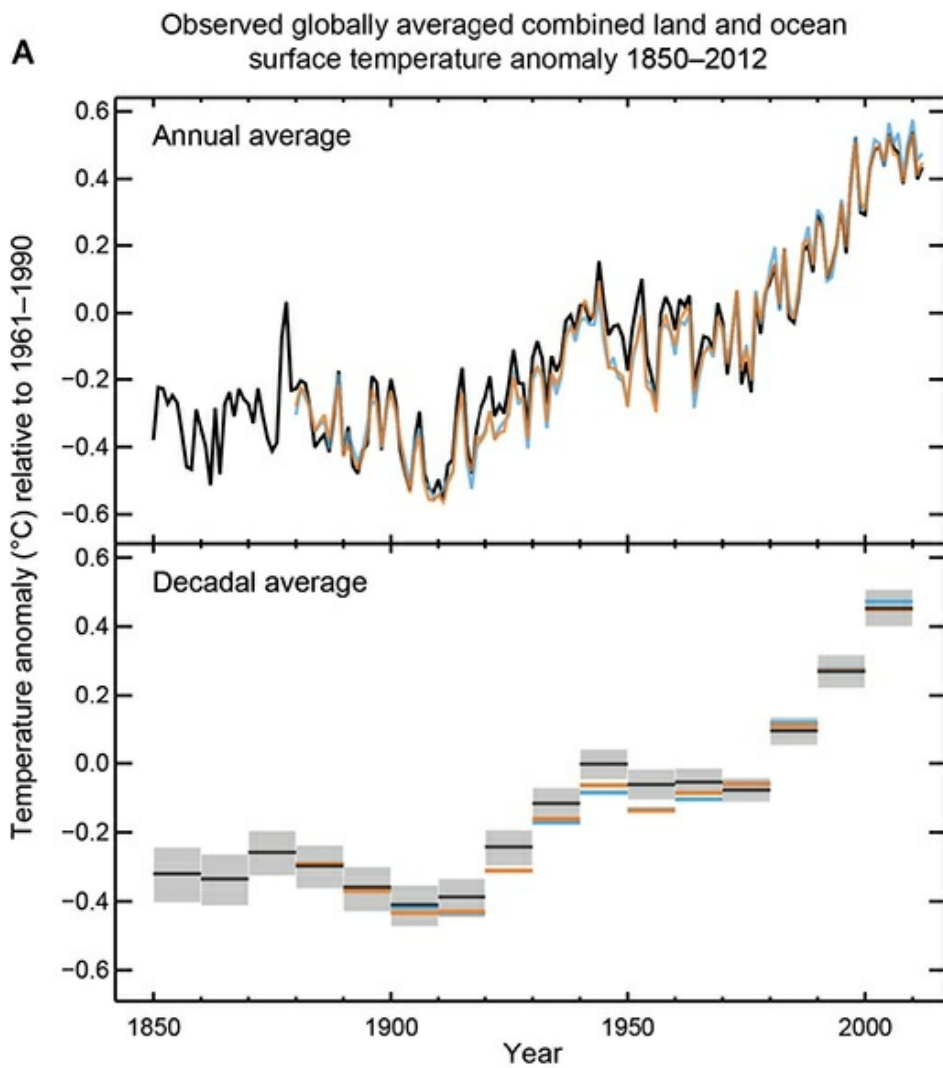


Figure 24.1. Rates of global warming showing A, observed global mean combined land and ocean surface temperature anomalies, from 1850 to 2012, and B, map of the observed surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression. Grid boxes where the trend is significant at the 10 percent level are indicated by a + sign. Adapted from IPCC 2013.

RIISING SEA LEVELS

Similar to rising global temperatures, the rate of sea level rise since the mid-nineteenth century has been greater than for any period during the previous two millennia (IPCC 2013). Between 1901 and 2010, global mean sea level rose by 0.19 m, and the rate of increase was almost twice as high in recent decades. Global mean sea level rise is considered a result of multiple drivers including ocean thermal expansion (the physical increase in volume of water as it warms) and changes in the Greenland and Antarctic ice sheets, but since the early 1970s, the combined effects of glacier mass loss and ocean thermal expansion explains about 75 percent of the observed mean sea level rise (Church et al. 2013). Global mean sea level will continue to rise during the next century. Under all RCP scenarios, the rate of sea level rise will exceed that observed during the pasty forty years as a consequence of increased ocean warming and continuing loss of mass from glaciers and ice sheets. For RCP8.5, the relative rise in sea level by the end of the century is predicted to be between 0.52 and 0.98 m, with a late-century rate of 8 to 16 mm per year. Under future projections, thermal expansion accounts for 30 to 55 percent global mean sea level rise, and glaciers 15 to 35 percent. One of the largest drivers of future sea level change is an increase in surface melting of the Greenland ice sheet that will eventually exceed any increase in snowfall. It is clear that these changes are most relevant for coastal breeding birds, and an estimated 70 percent of the coastlines worldwide are projected to experience significant sea level change (Church et al. 2013). Sea level rise of such magnitude will cause inundation of coastal areas, flooding, erosion, saltwater intrusion into estuaries and other freshwater coastal habitats, rising water tables, and habitat loss (Nicholls et al. 2007).

REPRESENTATIVE CONCENTRATION PATHWAYS

To predict future changes in climate, scientists use a variety of climate models based on a set of scenarios called Representative Concentration

Pathways (RCPs) (Moss et al. 2008). In all RCPs, atmospheric CO₂ concentrations are higher in the year 2100 relative to present day. RCPs represent four greenhouse gas concentration trajectories and possible climate futures, all of which depend on the amount of greenhouse gases emitted in the years to come. The four RCPs are named after a range of radiative forcings that capture the change in energy in the atmosphere caused by GHG emissions in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m², respectively).

REDUCED SNOW COVER AND RETREATING ICE

In many regions of the world occupied by birds, snow and ice cover the landscape during different parts of the year; these regions are considered part of the **cryosphere**. The cryosphere represents those portions of Earth's surface where water is in solid form, including ice sheets, snow cover, glaciers, and permafrost. The components of the cryosphere play a crucial role in the Earth's climate and are some of the most sensitive to climate shifts. Over the last two decades, glaciers have diminished almost worldwide, the Greenland and Antarctic ice sheets have been losing mass, and Arctic sea ice and Northern Hemisphere spring snow cover have decreased in extent (IPCC 2013). Around the world, the rate of ice loss from glaciers has been increasing in recent years ([fig. 24.3](#)). Glaciers in the tropics and midlatitudes are particularly vulnerable and are retreating; striking examples of tropical glacier retreat have been documented in the Andes Mountains and in Indonesia and Kenya (Klein and Kincaid 2006, Rostom and Hastenrath 2007). In other regions, the glaciers of the Alps have lost nearly 50 percent of their surface area and mass since 1850 (Zemp et al. 2006), and 80 percent of glaciers in Montana's Glacier National Park have diminished significantly (Hall and Fagre 2003). At the same time that many glaciers have retreated, a similar pattern is playing out with sea ice. Between 1970 and 2012, Arctic sea ice extent decreased at a rate of 3.5 to 4.1 percent per decade, resulting in the loss of almost half a million km² of sea ice per decade (Vaughan et al. 2013). This decrease in Arctic sea ice has been most rapid in summer. In Antarctica, the story is more complicated, with some regions increasing and some decreasing in sea ice extent.

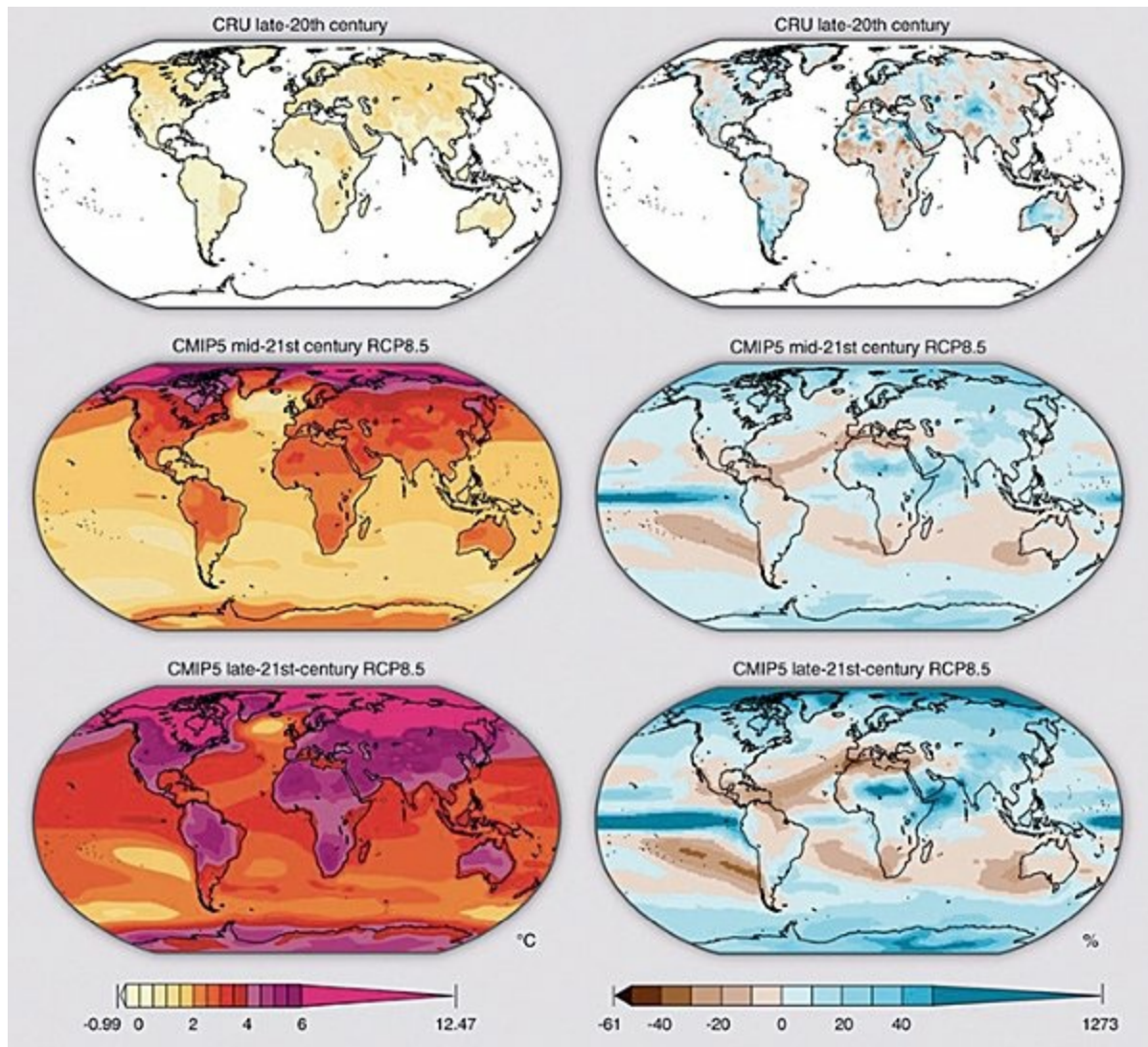


Figure 24.2. Observed and projected changes in annual temperature and precipitation for the late twentieth century calculated as 1986–2005 minus 1956–1975 (*top panel*). Differences in the mid-twenty-first-century period of the CMIP5 RCP8.5 ensemble, calculated as 2046–2065 minus 1986–2005 (*middle panel*). Differences in the late-twenty-first-century period of the CMIP5 RCP8.5 ensemble, calculated as 2081–2100 minus 1986–2005 (*bottom panel*). Values at the left and right extremes of the color bars give the minimum and maximum values (respectively) that occur across all of the periods. *Diffenbaugh and Field 2013, used with permission.*



Figure 24.3. Glacier recession has advanced globally, including in high-elevation tropical mountain ranges such as the Andes of South America. A, Ice loss between 1987 and 2011 is shown in red around the Pastoruri glacier in Peru's Huascarán National Park, in the Cordillera Blanca of the Andes. Glacier recession was determined by measuring changes in the Normalized Difference Snow Index between 1987 and 2011 Landsat TM imagery. B, Stream flows are strongly altered by increasing glacial recession rates, with negative ecological consequences for downstream habitat. C, Peatland patches near glaciers, an important high-elevation Andean habitat, are fragmenting and undergoing attrition. In the image, researchers collect peat samples. D, Observers visit the receding Pastoruri glacier on a day trip with a climate change theme. Image analysis and photographs by Molly H. Polk and Kenneth R. Young.

Both persistent and seasonal snow cover are important features for many cold-adapted birds, but snow cover regimes have changed dramatically in many parts of the Northern Hemisphere. Since the 1970s, snow cover extent

has decreased 1.6 percent per decade for March and April, and 11.7 percent per decade for June (Derksen and Brown 2012). During this period, snow cover extent in the Northern Hemisphere did not show a statistically significant increase in any month. At the same time, permafrost temperatures have increased in most regions since the early 1980s. As an example, there has been a considerable reduction in permafrost thickness and areal extent in many parts of northern Russia.

As is the case for the Earth's changes in precipitation, it is difficult to make robust predictions regarding changes in the cryosphere. It is nonetheless considered very likely that Arctic sea ice cover will continue to shrink, Northern Hemisphere spring snow cover will decrease, and global glacier volumes will diminish during the twenty-first century as global temperature rises. Year-round reductions in Arctic sea ice extent are projected to range from 43 percent (RCP2.6) to 94 percent (RCP8.5) (IPCC 2013). By the end of the twenty-first century, the global glacier volume is projected to decrease by 15 to 55 percent for RCP2.6 and by 35 to 85 percent for RCP8.5 (with medium confidence in these predictions). The area of Northern Hemisphere spring snow cover is projected to decrease by 7 percent for RCP2.6 and by 25 percent in RCP8.5 over the next 100 years. It is virtually certain that permafrost extent at high northern latitudes will be reduced as global mean surface temperature increases, with projected decreases between 37 percent (RCP2.6) and 81 percent (RCP8.5).

EXTREME WEATHER: HEAT WAVES, DROUGHT, AND FLOODS

Changes in extreme weather and climate events, such as heat waves and droughts, are the most direct way bird populations can be affected by climate change. Climate change has already increased the number and strength of some of these extreme events (IPCC 2013). Although changes in the frequency and magnitude of extreme events have been observed, it is difficult to attribute a single extreme event (drought, storm, or flood) to climate change (Trenberth et al. 2015). As the characteristics of Earth's climate shift, however, we can expect a higher likelihood of certain anomalies. As expected with warming temperatures, unusually cold days and nights and frosts have become less frequent, while hot days and nights have become more frequent at a global scale (Christidis et al. 2011, IPCC 2013). This increase in the

frequency of hot days has raised the concern of more frequent and intense heat waves (Duffy and Tebaldi 2012). For example, the summer of 2003 in Europe was the warmest summer on record since 1540, the record broken only by another heat wave seven years later—the 2010 heat wave in Russia (Barriopedro et al. 2011). The likelihood of such “mega” heat waves is predicted to increase by a factor of 5 to 10 within the next 40 years (Barriopedro et al. 2011). Higher temperatures lead to increased rates of evaporation, and even in regions where precipitation has not declined, increases in temperatures and in surface evaporation can promote drought conditions. Regions with increased droughts include the Sahel of Central Africa, the Mediterranean, southern Africa and parts of southern Asia (IPCC 2013). In North America, there has been an increase in the concurrence of droughts and heatwaves across the United States (Mazdiyasni and AghaKouchak 2015), and there is growing concern that the future American Southwest and Central Plains will experience “megadrought” conditions far beyond the contemporary experience of bird populations inhabiting Western North America (Cook et al. 2015).

In addition to the growing conservation concern associated with drought, there is a strong possibility that many land regions are experiencing an increasing frequency or intensity of heavy precipitation events, which also pose conservation risks. Increased amounts of water vapor and atmospheric moisture have caused higher numbers of precipitation events and increased precipitation intensity leading to increases in flooding risk in many regions. However, the risk of flooding is not increasing homogeneously around the globe. Regions experiencing increases in the number and intensity of precipitation events are eastern parts of North and South America, northern Europe, and north-central Asia (IPCC 2013). Extreme precipitation events over most of the midlatitude and tropical regions will very likely become more intense and more frequent by the end of this century (IPCC 2013).

CHANGES IN SEASONALITY: EARLIER SPRINGS, DELAYED AUTUMNS

Climate-mediated seasonal transitions play a crucial role in avian life cycle events. For example, the onset of spring in temperate ecosystems is strongly associated with birds arriving to their breeding grounds, defending their territories, finding a mate, and building a nest. In many regions, however,

climate change has altered the timing of these seasonal transitions, resulting in earlier springs caused by rising global temperatures (McCabe et al. 2012, Ault et al. 2015). Across the coterminous United States, regional trends in spring leaf emergence have shifted earlier from 0.8 to 1.6 days per decade, while flower emergence has shifted from 0.4 to 1.2 days earlier per decade (Ault et al. 2015). Many of these trends, however, are influenced by variations in climate variability (e.g., the El Niño-Southern Oscillation) and vary strongly across regions where spring onset has even been delayed in some areas (Schwartz et al. 2013). Future climate projections suggest that earlier springs will continue into the future, with estimates of a 23-day shift across the United States under the RCP8.5 scenario (Allstadt et al. 2015). Earlier spring onset can increase the vulnerability of plants and animals to subfreezing temperatures; these “false spring” events can damage new plant growth and potentially impact early arriving birds. The risk of false spring events is expected to increase in regions such as the Great Plains and Upper Midwest (Allstadt et al. 2015). Although there is strong consensus that a warming world promotes earlier springs, less is known about autumn phenology (Gallinat et al. 2015). In general, there are indications that leaf senescence has been delayed by rising global temperatures (Menzel et al. 2006, Ibanez et al. 2010), and combined with earlier springs, this represents a general extension in the growing season for many ecosystems.

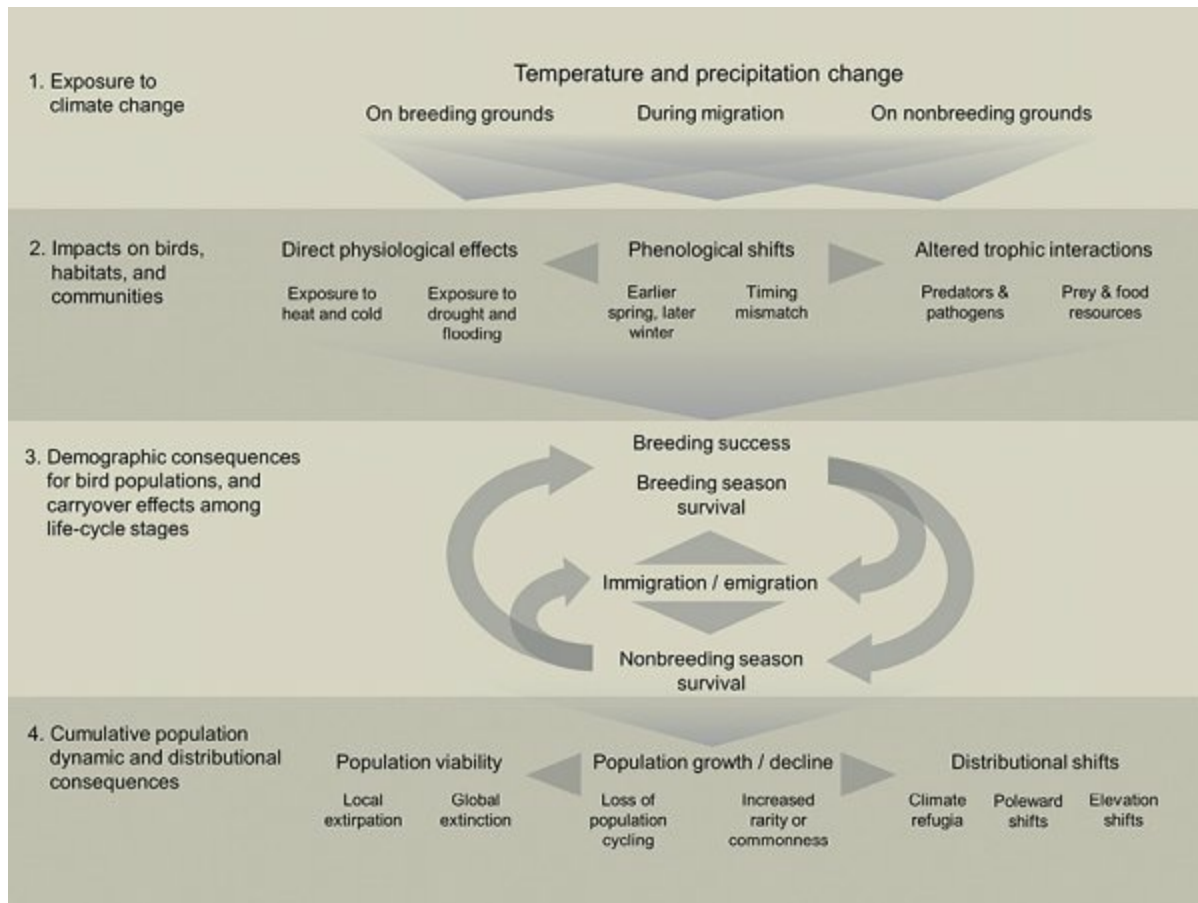


Figure 24.4. (1) Exposure to climate change can affect birds directly and indirectly through (2) physiological impact on the bird, changes in its habitat, and changes in its ecological community and relationships with other species. These effects in turn can (3) alter the demography of bird populations by increasing or decreasing rates of birth, death, immigration, and emigration; and effects during one stage of the life cycle may carry over into later stages. Ultimately, (4) these cumulative demographic consequences shape overall population growth and decline, which can cause shifts in a species' geographic distribution through local colonization and extirpation processes, as well as changes in long-term viability including the possibility of extinction. The impacts of climate change at stage 4 can also feed back into stages 2 and 3, for example by influencing community composition and interactions with other species.

A BIRD'S EYE VIEW OF CLIMATE CHANGE

As we have seen, modern climate change has resulted in significant changes in global temperatures, precipitation patterns, sea levels, extreme weather events, and seasonality. Bird populations in all regions of the globe, and in all terrestrial and ocean habitats, are likely to be affected by these ongoing changes. This is because the ability of birds to survive, reproduce, migrate, and persist over the long term are all influenced by weather and climate (fig. 24.4). Weather represents atmospheric conditions that birds must adjust to

over short periods of time, whereas climate comprises characteristics averaged over relatively long periods of time (e.g., over several decades). Weather and climate both shape the habitats and ecological communities in which birds flourish and to which they are adapted ([chapters 18](#) and [22](#)). Ultimately, climate change has the potential to affect birds directly through extreme events or long-term changes in climatic conditions, and indirectly by reshaping their habitats.

TERRY L. ROOT



Terry L. Root is a senior fellow emerita at the Woods Institute for the Environment at Stanford University and a professor, by courtesy, in the Biology Department. She researches how wild animals and plants are changing with climate change. *Photo with permission from T. Root.*

The work of Dr. Terry L. Root focuses on how wild animals and plants are changing with climate change. Her early research focused on the role of climate on bird metabolic constraints and winter ranges, and was an early vindication of the use of citizen science in documenting bird ranges. Her

current focus is on assessing the mass extinction of species with warming and the broader attribution of human impacts on shifting ranges and phenology for birds, mammals, and plants. She has been a lead author for the Third (2001) and Fourth (2007) Assessment Reports of the IPCC. Root is widely credited for early theories on how bird ranges were constrained by climate and has received numerous recognitions including the Spirit of Defenders Award for Science, Aldo Leopold Leadership Fellow, Pew Scholar in Conservation and the Environment, and a Presidential Young Investigator Award from the National Science Foundation.

Climate change can impact a bird population by having some direct or indirect effect on one or more of the fundamental demographic processes: birth, death, immigration, and emigration (Jenouvrier 2013). It is through these four processes that populations are structured, grow, decline, colonize new areas, or become extirpated ([chapter 21](#)). Because the geographic distribution of a species is nothing more than the cumulative result of many local extirpation and colonization events, climate variability influences species distributions through these demographic processes ([chapter 4](#)). Therefore, in asking how bird species might be affected by modern climate change, it is useful to consider different ways in which climate variability can influence demography and to consider how changes in demographic rates may shape populations as a whole.

How well birds survive and reproduce is strongly determined by access to critical resources such as food and shelter. These resources can be influenced by weather and increasing variability in climate. The most direct effects of climate variability may come during extreme events, when unusually cold, hot, wet, or dry spells expose birds to conditions that cause physiological stress. Indirect climatic effects include changes in food availability caused by, for example, influences on plant and invertebrate prey. As climate changes and extreme events become more common, these stresses may increase. Climate change may also cause changes in populations of predators and diseases, or change the exposure of bird populations to these natural enemies by modifying habitats or driving distributional changes that increase range overlap.

Ultimately, the effect of climate change on birds may be expressed in a variety of ways at different times of year, different stages of an organism's

life history, in different geographic regions, and cumulatively over longer periods of time (fig. 24.4). For example, for the Black-throated Blue Warbler (*Setophaga caerulescens*), climate influences both adult survival on the Caribbean wintering grounds and fecundity on the temperate breeding grounds more than a thousand miles distant. Both of these effects contribute to overall population dynamics, which are consequently linked to long-term climate fluctuations in the Northern Hemisphere (Sillett et al. 2000). Cases like this one illustrate how climate change may influence a given bird species at multiple stages along the life trajectory. There are also ways in which these influences may carry over into subsequent life stages and potentially interact with one another in complex ways, sometimes with unexpected outcomes in terms of overall population growth or decline.

EARLIER ARRIVAL AND CHANGES IN MIGRATION PHENOLOGY

Phenology is the timing of regular life history events such as arrival to breeding grounds and nest-building in birds or annual fruiting and leaf-out events in plants. Climate influences phenology in complex ways, and for birds, the most visible aspect of phenology is migration (Berthold et al. 2003, Newton 2010). The advancement of spring phenology has been one of the strongest signals of modern climate change and has important implications for bird migration (Walther et al. 2002, Cox 2010). Although day length is considered the ultimate driver of when birds begin to migrate, weather and climate can influence departure from wintering grounds, migration speed, and, ultimately, arrival to breeding grounds. In both Europe and North America, the timing of arrival to the breeding grounds has been linked to spring temperature and precipitation, large-scale climate variability (e.g., North Atlantic Oscillation), and wind speed and direction (Knudsen et al. 2007). Using data from banding/ringing stations, migration studies focus on long-term trends in **first arrival** or **median arrival** dates. First arrival dates are calculated to capture the front of the migration and the earliest arriving individuals, whereas median arrival dates reflect the arrival of the bulk of the population. Across multiple bird species and in many locations across the world, the earliest arriving individuals are arriving to their breeding grounds some six to eight days earlier over the past thirty years, while the rest of the population are arriving four to five days earlier (Pearce-Higgins and Green

2014; see the box on [page 762](#)). Not all species, or even populations within species, are showing similar advancements, but the systematic earlier arrival to the breeding grounds is strong evidence that birds are responding to earlier springs throughout the Northern Hemisphere.

The influence that climate has on migratory phenology is complicated by the distance a species must travel from overwintering to breeding grounds. Short-distance, temperate migrants are thought to overwinter in regions that have the best mixture of tolerable local winter conditions while still providing close access to resources on their breeding grounds (Somveille et al. 2015). As a result, the advancement in spring arrival for short-distance migrants is a direct consequence of warming temperatures and the earlier onset of spring in mid- and high latitudes (Swanson and Palmer 2009). For long-distance migrants, however, it is more likely that climatic conditions on overwintering grounds and migratory stopovers are influencing rates of migration. Studies on Pied Flycatchers (*Ficedula hypoleuca*) and Barn Swallows (*Hirundo rustica*) have shown that arrival to the breeding grounds in Europe is associated with weather conditions on the wintering grounds in Africa (Both 2010). Similarly, the timing of spring departure for American Redstarts (*Setophaga ruticilla*) overwintering in Jamaica is a product of rainfall, with wet springs promoting increased arthropod abundance and increased body condition, and leading to earlier departure for breeding grounds in North America (Studds and Marra 2007, 2011) ([fig. 24.5](#)). Following departure from overwintering grounds, long-distance migrants are more susceptible to variation in vegetative productivity and extreme weather events, such as drought, that may contribute to prolonged stopover duration (Tottrup et al. 2012). Weather conditions may indeed help facilitate earlier departures, but for species that have to travel only short distances for migration, the conditions on overwintering grounds may be serving as a proxy for the conditions of their nearby breeding grounds.



Figure 24.5. The timing of spring departure for American Redstarts (*Setophaga ruticilla*) overwintering in Jamaica is strongly influenced by rainfall, with wet springs promoting increased arthropod abundance, increased body condition, and leading to earlier departure for breeding grounds in North America. Even though long-distance migrants have migratory tendencies that are driven by non-climatic cues like photoperiod, climate conditions on their nonbreeding grounds and migratory stopovers can influence their arrival to breeding grounds. Photo taken by Dan Pancamo, Quintana, Texas, November 30, 2010, licensed under the Creative Commons Attribution-Share Alike 2.0 Generic license, https://commons.wikimedia.org/wiki/File:American_Redstart_of_Quintana_Texas1.jpg.

As many birds are shifting their spring arrival, so too are nesting dates and breeding cycles shifting earlier. An earlier timing of breeding activity has led to the growing conservation concern of a decoupling between bird arrival and nesting with the availability of crucially important prey such as insects. This decoupling between the phenology of birds and the resources they depend on is referred to as **phenological mismatch** (Both et al. 2004), and these mismatches have important effects on both individual birds and populations (Pearce-Higgins and Green 2014). Studies on long-distance migrants have found that a failure to advance spring phenology could contribute to population declines (Both et al. 2006). Recently, however, studies have shown that the impact of phenological mismatches can be lessened by high local food availability (Dunn et al. 2011) and differences across habitats (Burger et al. 2012). In addition, population-level consequences may not be realized because of reduced competition among surviving juveniles during years when the mismatch is particularly strong (Reed et al. 2013). Altogether,

there is strong potential for important consequences of phenological mismatch for birds and their prey, but the full extent of these consequences is likely to be influenced by factors such as habitat quality, seasonality of food resources, and competition.

MOVING POLEWARD AND SEEKING HIGHER GROUND IN A WARMING WORLD

In the face of environmental change, species can evolve new physiological tolerances to cope with altered climatic conditions, or they can move to maintain existing associations with the particular climates that define each species' **climatic niche**. As climate change occurs, we might expect vagile taxa, such as birds, to shift their distributions as they track their climatic niches through time. As such, the past forty years of rapid warming represents a large-scale experiment on how climate change influences bird ranges from regional to continental scales. If bird ranges are more or less limited by climate, then as climate conditions change, one would predict that bird distributions would follow (Pearson and Dawson 2003). An aspect of species ranges that are particularly sensitive to climate are **range boundaries** (Thomas 2010), and northerly range boundaries for many birds in the northern hemisphere tend to be correlated with long-term gradients in temperature and precipitation (Root 1988) ([fig. 24.6](#); see the box on [page 760](#)). A fundamental prediction of climate change is that as global temperatures rise, bird range boundaries should respond by shifting to higher latitudes, i.e., toward the poles. These poleward shifts have been documented for birds in various regions of the world (Chen et al. 2011), including wintering and breeding birds in North America and Europe (Hitch and Leberg 2006, La Sorte and Thompson 2007, Mason et al. 2015). Based on multiple studies across the Northern Hemisphere, there has been a consistent poleward shift in bird ranges of 0.76 km per year, resulting in a mean shift of 15 km over the past 20 years (Pearce-Higgins and Green 2014). This does not mean that all birds have shifted northward, but it does suggest a trend that the majority of bird ranges have shifted in a direction that is concordant with a response to a warming world.

Past and future shifts in bird species ranges are likely to be more complex than poleward shifts. Across large geographic scales, birds respond differently to climate change because of species-specific sensitivities as well

as the role of climatic factors other than temperature that might show more complex variability over space and time (precipitation in particular). In support of the idea that range shifts can show complex directionality, recent studies have found that range changes do not always follow a poleward trajectory, and multidirectional range shifts in response to climate change are common for birds across the United States, Britain, and Australia (VanDerWal et al. 2013, Gillings et al. 2015, Bateman et al. 2016). In addition, it may take birds many years to “track” their suitable climate space. For example, a continental assessment of range shifts in wintering birds in North America found that individual species displayed highly variable responses to changes in winter temperature, and that many bird ranges took over 30 years to catch up to their changing climatic niche (La Sorte and Jetz 2012).

JAMES PEARCE-HIGGINS



James Pearce-Higgins is the Director of Science at the British Trust for Ornithology. He researches the effects of climate change on bird populations and informs programs in bird conservation and climate change adaptation. *Photo with permission from the British Trust for Ornithology. Photo by Stephen H. Scheider.*

Dr. James Pearce-Higgins serves as the science director for the British Trust for Ornithology (BTO). Dr. Pearce-Higgins provides strategic oversight of BTO science and climate change research. His research has focused on changes in the abundance, distribution, and demography of bird populations and understanding the causes of population change to inform what is required to manage species and habitats sustainably. BTO's climate change research involves documenting the impacts of climate change on bird biodiversity, evaluating future impacts, and informing climate change adaptation efforts. Dr. Pearce-Higgins leads several multi-organizational efforts in climate change research throughout Europe. Before joining the BTO, Dr. Pearce-Higgins led a wide range of research projects on the impacts of weather and seasonality on upland bird demography. His current research in both applied and basic ornithology involves documenting the effects of climate change on avian biodiversity, undertaking projections of the future impact of climate change on bird distributions and abundance, and informing the development of climate change adaptation. He leads several research consortia on the ecological effects of climate change and coauthored *Birds and Climate Change: Impacts and Conservation Responses*.



*Figure 24.6. Many wintering birds of North America have shifted northward over the past three decades. The Northern Cardinal (*Cardinalis cardinalis*) is a common denizen of people's backyards and has demonstrated a general shift northward in its range over time, potentially taking advantage of milder winters. Photo taken by John Capella in Fishers, IN.*

The influence of climate change on bird ranges is perhaps nowhere more evident than in montane ecosystems. Similar to poleward shifts, upslope shifts in elevation in response to warming temperatures are considered one of the strongest lines of evidence that species are responding to modern climate change (Parmesan 2006), but unlike range shifts, which are measured in kilometers, elevational shifts are much smaller and more variable. Upslope shifts in bird ranges average roughly 0.33 m per year, equivalent to a 6.6 m shift over 20 years (Pearce-Higgins and Green 2014). This may not seem like much, but changes over longer time periods can be significant. Over nearly a century of climate change, birds in the Sierra Nevada of California shifted their elevational ranges as they tracked long-term changes in precipitation and temperature (Tingley et al. 2009). In this case, rising temperatures pushed bird populations upslope while increased precipitation pulled them downslope, resulting in a complex mixture of elevational shifts for individual species and regions (Tingley et al. 2012) ([fig. 24.7](#)). Similar patterns of upslope and downslope shifts over time have been found for birds in other montane ecosystems such as the Swiss Alps (Maggini et al. 2011). Small or insignificant shifts in elevation suggest that birds are not moving fast enough to track climate up in elevation, and in the case of montane environments, birds may be more limited by habitat availability or constrained in their dispersal abilities by the topographic complexity (Elsen and Tingley 2015). In addition, differences exist between temperate and tropical locations. There is evidence that tropical montane birds are more responsive to changes in mean temperature than temperate zone montane birds, moving upslope at faster rates and showing less lag with temperature changes (Forero-Medina et al. 2011, Freeman and Freeman 2014).



Figure 24.7. Bird species of the Sierra Nevada Mountains of California have responded to climate change by changing their distributions across elevational gradients. Changes in precipitation and temperature are complex and have resulted in both upslope and downslope changes in bird distributions. Over 100 years of change, birds like A, Western Scrub Jay (*Aphelocoma californica*) have shifted downslope, while other birds like B, Red-winged Blackbird shifted upslope (*Agelaius phoeniceus*). Western Scrub Jay photo taken by Morgan Tingley. Red-winged Blackbird photo taken by Alan Wilson, September 26, 2006, licensed under the Creative Commons Attribution-Share Alike 2.0 Generic license, https://commons.wikimedia.org/wiki/File:Red_winged_blackbird_-_natures_pics.jpg.

EXTREME WEATHER AND ITS INFLUENCE ON BIRD POPULATIONS

Increasing frequency of extreme weather events such as drought, floods, and heat waves poses the most direct threat of climate change for bird populations. As these weather events are expected to become more severe and frequent in the coming years, understanding their impacts on bird demography and population viability is increasingly important. The probability of an individual bird successfully reproducing (or failing to reproduce) can be influenced by extreme weather events, with critical implications for populations as a whole.

Perhaps the most obvious effect of extreme weather on birds is drought. Although birds occupying warm and arid regions are adapted to variability in precipitation, the increasing frequency and magnitude of these extreme weather events can have far-reaching demographic consequences. For example, populations of the Florida Snail Kite (*Rostrhamus sociabilis plumbeus*), an endangered bird, are highly sensitive to droughts; during drought years, older adults are less likely to breed, while younger kites are more likely. This shift has had lasting effects on the structure of the population, as more experienced birds failed to breed during harsh environmental conditions (Reichert et al. 2012). The southwestern United States has been experiencing severe drought conditions, and in one case a Burrowing Owl (*Athene cunicularia*) population declined by 98 percent over a 16-year period as a result of the negative effects of decreased precipitation and increased air temperatures on physiological condition, reproductive output, and breeding phenology (McDonnell-Cruz and Wolf 2015). Across entire regions and countries, widespread drought and heat waves can impact entire bird communities. In the Great Plains of the United States, drought negatively affected bird communities by reducing the abundance and richness of Neotropical migrants by 13 percent and 6 percent, respectively (Albright et al. 2010). Similarly, a six-month heat wave in 2003 halted or reduced population growth for many bird species in France (Jiguet et al. 2006).

Just as birds are affected by droughts in arid regions, birds occupying the cryosphere can be affected by harsh winters and snowstorms. Extremely harsh winters can reduce juvenile and adult bird survival rates and compromise population persistence through mass mortality (Altwegg et al. 2006, Link and Sauer 2007). In arctic and antarctic ecosystems, snowstorms

can have lasting effects on nest survival and overall reproductive success. For example, the frequency of snowstorms explained almost 30 percent of daily nest and colony productivity for Antarctic Petrels (*Thalassoica antarctica*) over a 20-year period (Descamps et al. 2015). Notably, chicks in poor condition were more likely to die during a snowstorm than chicks in good condition. By their very nature, however, extreme weather events such as storms normally occur over short time periods and may not always have lasting effects on bird survival. A detailed study of Black-tailed Godwits (*Limosa limosa limosa*) found that when a spring snowstorm coincided with their spring migration, many individual birds showed reverse migration, delayed breeding, and elevated metabolic costs. However, overall breeding success for the population was unaffected, and there was little carryover effect as a result of these late snowstorms (Senner et al. 2015). Ice-dependent seabirds, such as Southern Fulmars (*Fulmarus glacialisoides*), that forage near the ice edge must deal with increasingly extreme years when sea ice area is reduced and the distance between foraging areas and the breeding colony is high (Jenouvrier et al. 2015) (fig. 24.8). During these extreme years, foraging trips were greater in distance and duration, resulting in less food delivered to chicks, reduced body condition, low breeding success, and reduced population growth rate. More experienced and successful breeders were better able to deal with these extremes, and as a result, years characterized by extreme loss of sea ice tended to exacerbate differences in individual behavior and flexibility (Jenouvrier et al. 2015). Similarly, projected future changes in ice conditions of the antarctic ecosystem are dire for Emperor Penguins (*Aptenodytes forsteri*), with models suggesting that by 2100 penguin populations will be suffering severe population declines resulting in a 19 percent decline of the global population (Jenouvrier et al. 2014) (fig. 24.8). Clearly, the ability of bird populations to adapt to extreme events is crucial to their long-term survival.

CLIMATE CHANGE AND BIRD COMMUNITIES

Climate exerts a strong influence on which species are present in a given place, and how bird communities characterized in this way change over time and across regions. That is, bird **species composition** is shaped in part by climate conditions and climate variability, along with other important factors (chapter 22). As the phenology and ranges of birds change over time, climate

strongly influences how species interact with one another and with their environments and, ultimately, helps shape bird communities. Modern climate change is therefore likely to induce important changes in bird communities. Changes in species composition can be characterized in a number of ways. Some of the most familiar attributes of species composition in ecology are the related concepts of **species richness** and **diversity** ([chapter 22](#)). Simply put, some bird communities contain more species than others. Even given similar numbers of species, different bird communities may be composed of entirely different species, and thus function very differently. These patterns can be characterized using measures of **species turnover** and **beta-diversity**, which quantify changes in species composition over time or space. Ecological differences among communities can also be measured by examining the characteristics of their constituent species, such as diet or dispersal abilities. For example, high-latitude bird communities tend to have higher proportions of migratory species than do communities closer to the equator.

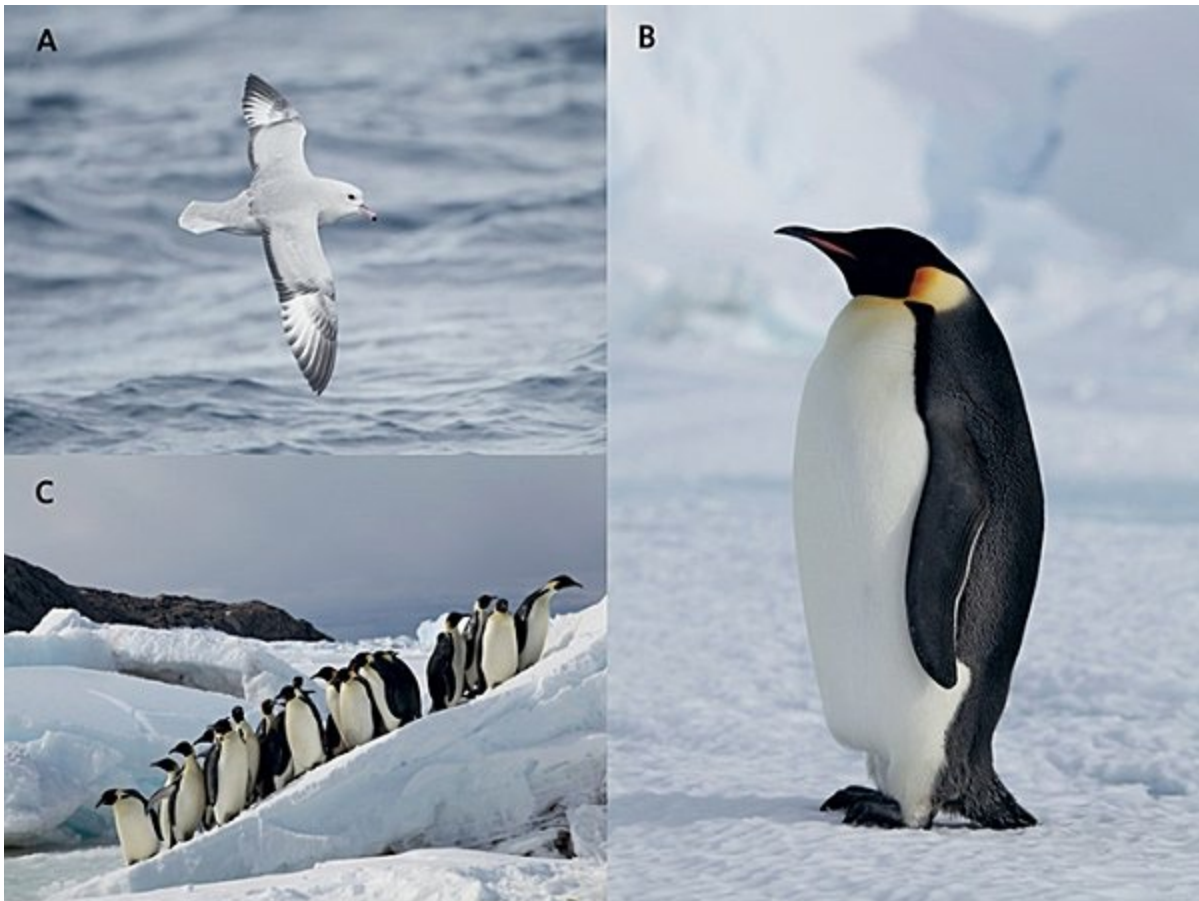


Figure 24.8. Ice-dependent seabirds, such as A, Southern Fulmar (*Fulmarus glacialis*) and B, Emperor Penguin (*Aptenodytes forsteri*) that forage near the ice edge must deal with increasingly extreme years when sea ice area is reduced and the distance between foraging areas and the breeding colony is high. Expected future changes in ice conditions of the Antarctic ecosystem suggest that C, large colonies of Emperor Penguins are likely to face catastrophic population declines. Penguin photos by Erica Fitzpatrick. Southern Fulmar photo by JJ Harrison, May 28, 2012, licensed under the Creative Commons Attribution-Share Alike 2.0 Generic license, https://commons.wikimedia.org/wiki/File:Fulmarus_glacialis_in_flight_-_SE_Tasmania.jpg.

In this section we review how some of these community characteristics are expected to respond to climate change, what changes have already been observed in recent decades, and what the future might hold for bird communities. The detection of change in community characteristics over time and across large areas requires extensive, long-term data that are difficult or impossible for individual research teams to collect. The advent of **citizen science** programs, in which large numbers of people, often knowledgeable nonscientists, can contribute observations of birds, has aided such efforts immeasurably.

Changes in Species Richness, Functional Diversity, and Beta-Diversity

It is generally understood that bird species richness tends to be higher in warmer and wetter places than in cooler and drier places (chapter 4). The productivity of plants, which is usually higher under warm, humid conditions, has much to do with these patterns. For example, tropical rain forests have both very high plant productivity and very high bird species richness. These patterns produce expectations about the effects of climate change. For example, as climates warm in temperate regions, we might predict that species richness will increase, given no or little decline in precipitation. Similarly, reduced precipitation such as that predicted for some tropical regions may induce declines in species richness. Long-term data sets capable of detecting changes in richness over time are rare for tropical systems. In temperate regions such as Europe, long-term monitoring efforts have shown evidence of increasing species richness associated with increasing mean temperatures in recent decades (Davey et al. 2012).

Individual species respond in distinctive ways to climate change largely because relationships with the environment and behavioral repertoires vary from one species to another. That is, species differ from one another in

ecological characteristics or **functional traits**. For example, range shifts in response to changing climates may take much longer for sedentary species with little ability to disperse long distances than for highly migratory birds, and poor dispersers may be especially disadvantaged if their habitat is highly fragmented. Across whole communities, this may result in a filtering of species over time according to functional traits and habitat relationships. Community composition may thus shift toward species with traits that allow adaptation to new climate conditions and away from those with disadvantageous traits. As this happens, there is potential for the loss of **functional diversity**—that is, a reduction in the variety of different ecological roles that are played by the collection of species in a community. Research in Europe has shown that habitat generalists have responded to a warming climate more favorably than have habitat specialists, leading to bird communities increasingly composed of generalists, as specialists have declined (Le Viol et al. 2012).

Another way of using species traits to describe communities, which has particular relevance for assessing climate change responses, involves measuring mean climate conditions across a species' range. The **species temperature index** (STI), for example, represents mean temperature at all locations where a species is known to occur within a study region. The **community temperature index** (CTI) in turn represents the mean STI for all bird species found in a given community or location. Communities may be composed mainly of warm-adapted species (high CTI) or cool-adapted species (low CTI). Long-term increases in CTI have been observed in North America and Europe, reflecting a combination of northward colonization by southerly species, losses of northerly species, and changes in the abundances of both of these groups (Devictor et al. 2008, Princé and Zuckerberg 2014).

Species composition is not fixed through time or across landscapes, but reflects cumulative patterns of individual species distributions and distributional changes in response to species' environments and to one another. Because of this, ecological communities tend not to move across landscapes as units in response to environmental change. Instead, landscapes show complex shifting mosaics of species composition, and particular communities may be unique to their time and place. While not the only factor, climatic variation plays an important role in these dynamics. One important expectation is that if climate change favors particular kinds of birds—such as warm-adapted species, habitat generalists, and good dispersers—

then landscape-level, place-to-place diversity (**beta-diversity**) will decline, making different communities more similar and landscapes more homogeneous over time, even while species richness may increase locally. This observation has in fact been borne out in studies of European birds over the past two decades (Le Viol et al. 2012, Davey et al. 2013).

Future Bird Communities under Climate Change

Novel climate conditions that have no present-day analog are expected to occur over large areas before the end of this century, particularly in the tropics, and we might expect that landscapes with novel climate conditions will support novel aggregations of species (Williams and Jackson 2007). One way to test this is to forecast the range shifts of species expected under climate change scenarios, given their particular climatic tolerances. Geographic shifts in climate suitability can be forecast in this way with **species distribution models** (Franklin 2009) (fig. 24.9). The results of many such models for different species can be used to estimate potential changes in species richness and rates of species turnover at individual locations, and across large regions (Peterson et al. 2002, Stralberg et al. 2009, Lawler et al. 2009). Such studies have suggested that most present-day communities will change as individual species distributions shift in response to climate change, which is consistent with what has been observed so far (fig. 24.10). While some species gains are predicted in northerly regions and at high elevations, species losses are also predicted in tropical regions and at low elevations (Lawler et al. 2009). Some community compositions found today may no longer occur at any location after sufficient climate change has occurred. Conversely, many locations in the future will support novel, or so-called **no-analog** bird communities that are not today found anywhere—that is, they have no present-day analog (fig. 24.10).

Given that species composition in many places will be novel in the near future, we can also expect that the dominance or importance of different kinds of interactions among bird species will also shift, resulting in novel community dynamics. New community compositions may result primarily from within-range shifts in abundance and local occurrence, in such a way that species with already overlapping distributions will come into contact more or less frequently. In other cases, species with previously nonoverlapping distributions may undergo range shifts that bring them into

contact, contributing to the creation of no-analog communities. Some of the more negative effects that might occur in such cases could result from contact between closely related species or subspecies, which are more likely to compete for similar resources or, if sufficiently related, to hybridize. However, at least one study has estimated that the number of closely related species pairs expected to undergo climate-induced range overlap is relatively small (Krosby et al. 2015).

Climate change is likely to push ecosystems into new states, and under these conditions, the collections of species found in future landscapes may bear little resemblance to the bird communities of the past. New species combinations and interactions that are not yet within the experience of ecological science will be introduced, but these are difficult to predict, as are their ecosystem-level consequences. Of particular concern is the observation that there have been, to date, climate-change “winners” and “losers” among bird species, and the losers are expected to be increasingly threatened as climate change proceeds.

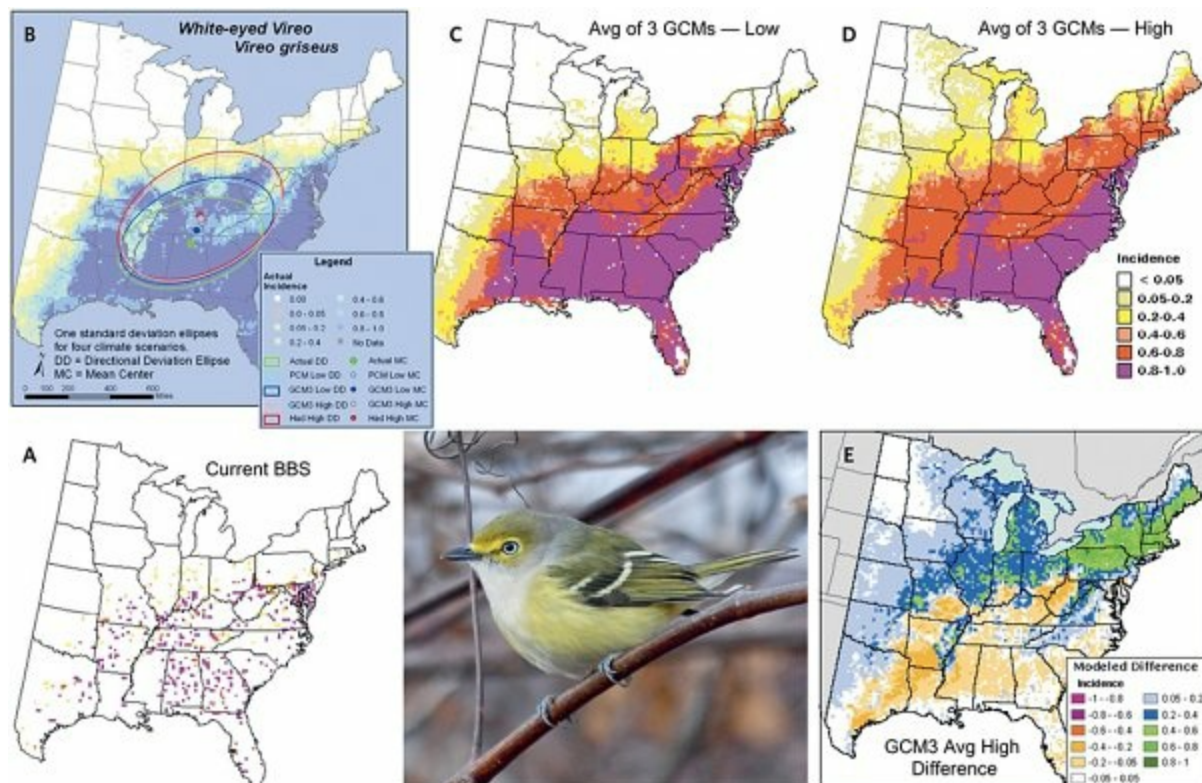


Figure 24.9. Species distribution modeling (SDM) can be a powerful tool for understanding how the distribution of suitable habitat and, potentially, the occurrence of a species is likely to shift in response to long-term changes in climate and other environmental factors. Here we illustrate this approach for

White-eyed Vireo (*Vireo griseus*), adapted from the US Forest Service's Climate Change Bird Atlas, an online tool that allows users to explore SDMs for 147 bird species in the eastern United States (Matthews et al. 2011, Landscape Change Research Group 2014). These models do not give predictions for species occurrence in specific locations or landscapes, but do provide a generalized expectation of broad distributional shifts in habitat suitability, given expected climate change by the end of the twenty-first century. *A*, documented occurrences of White-eyed Vireo collected during the annual US Breeding Bird Survey (BBS) were used to relate species presence to local temperature, precipitation, forest vegetation, topography, and other conditions. *B*, Locations with conditions similar to those where the species was observed were mapped across the eastern United States. Points and ellipses show the expected shift in the centroid of the distribution under different climate change models and scenarios (see *C* and *D*). *C* and *D*, Using these species-environment relationships, the distribution of suitable habitat under predicted future (i.e., end of the twenty-first century) climate conditions was projected using three different general circulation models and two different greenhouse gas emissions scenarios (a high- and a low-emissions scenario). *E*, Expected difference in habitat suitability between the present day and the future prediction periods, under the high-emissions scenario (orange-brown areas show expected decline, and blue-green areas show expected increase). *Photo of White-eyed Vireo by Larry Clarfeld, in Vermont, where the species is very rare, in November of 2014.*

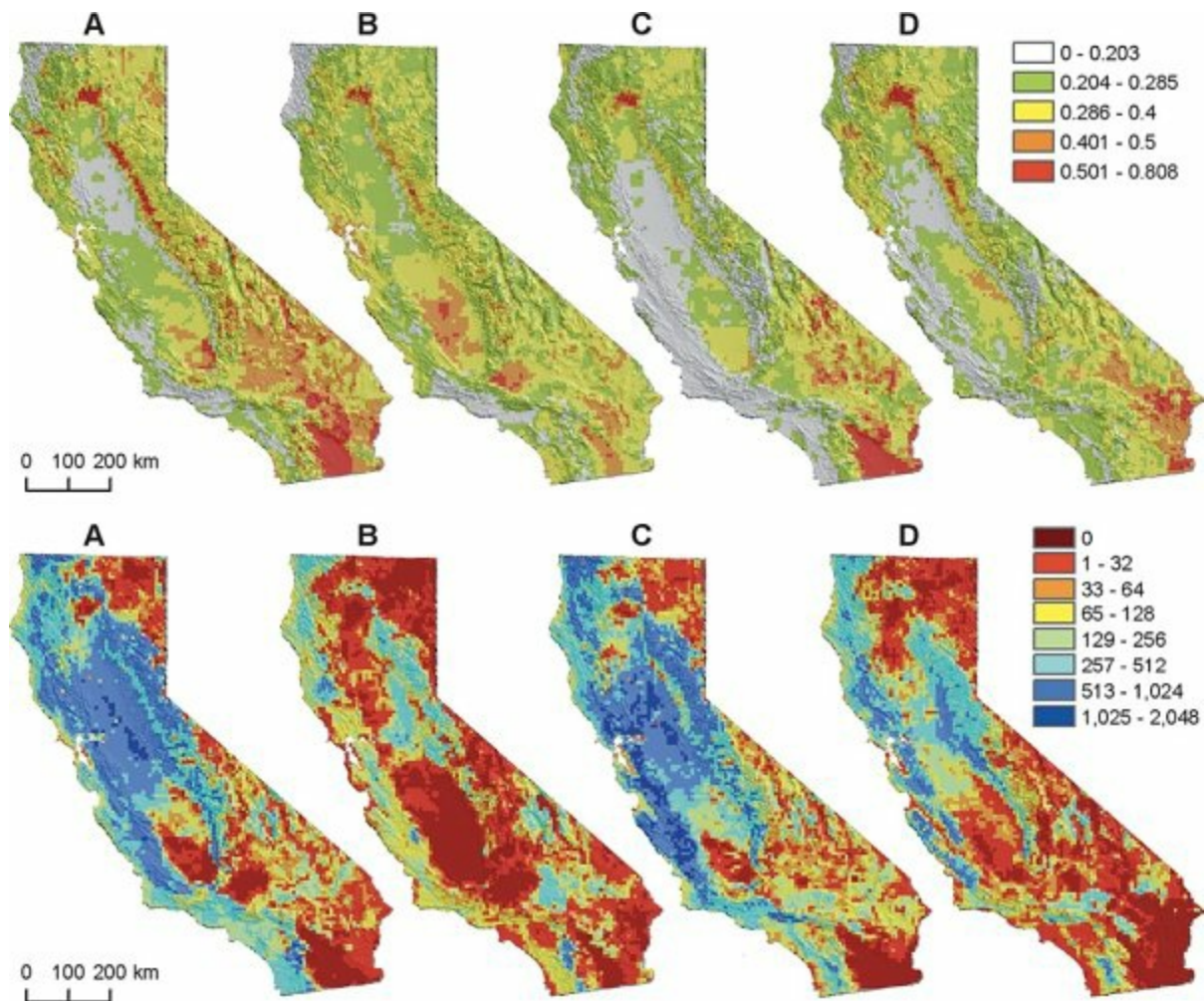


Figure 24.10. Change in bird species composition, and no-analog bird communities, predicted to result from future climate change in California (Stralberg et al. 2009). Differences in species composition

between the present day and the middle of the twenty-first century (2038–2070) were predicted on the basis of species distribution models. The models used vegetation and climate conditions, together with presence and absence information for 60 different bird species, to characterize species-specific habitat quality across the state. Then, climate models were used to project future distributions of high and low habitat suitability, given expected climate change. In the upper panels, higher values indicate more predicted difference between present-day and future species composition at a given location (in this case, measured with the Bray-Curtis index). In the lower panels, each location was compared with every other location in California to quantify how unique the predicted future bird community in that location was in relation to present-day communities across the state. Lower values indicate fewer present-day analogues, and therefore represent “no-analog” future communities. The different maps from left to right result from the use of different combinations of particular species distribution models and climate general circulation models. While different models produced slightly different results, overall geographic patterns of predicted change were similar (species distribution models: maps *A* and *C* used generalized additive models; *B* and *D* used maximum entropy models. Climate models: maps *A* and *B* used the National Center for Atmospheric Research (NCAR) Community Climate System Model 3.0; *C* and *D* used the Geophysical Fluid Dynamics Laboratory (GFDL) General Circulation Model CM2.1). Both climate models were based on the Intergovernmental Panel on Climate Change (IPCC) SRES A2 scenario, which is a medium-high emissions scenario.

CLIMATE-SMART CONSERVATION FOR BIRDS

Birds face multiple threats as a result of human activities, including the negative effects of habitat loss and fragmentation, invasive species, pollution, and overexploitation of birds ([chapters 25](#) and [26](#)). Climate change is now added to this list of environmental stressors with which bird populations must contend (Thomas et al. 2004). While variations in climate are nothing new, it is the pace of modern, human-caused changes in climate that conservation practitioners find alarming ([figs. 24.1](#), [24.2](#)). In this century, these changes are expected to be more rapid and extreme than the natural climatic variation that bird populations have faced in their recent evolutionary history (Williams et al. 2007). If species for which the new conditions are unfavorable cannot adapt on this time frame, they are likely to decline in abundance and perhaps become threatened with local extirpations or even extinction ([fig. 24.4](#)). Unfortunately, many species that are already affected by stressors such as habitat loss may also be vulnerable to climate change, and these effects may combine in ways that are more harmful than the individual effects in isolation.

A large tool kit of bird conservation strategies has been developed in response to the threats posed by human activities ([chapters 27](#) and [28](#)). The conservation community is currently in the early stages of expanding this tool kit to address climate change. This response falls largely in two areas. First, the underlying causes of modern climate change must be addressed through

efforts to reduce the amount of greenhouse gases being emitted and held in the Earth's atmosphere. These efforts are referred to as **climate change mitigation**. Ironically, some of these efforts, such as the conversion to greener energy sources like biofuels and wind power, may themselves have negative impacts on some birds. These trade-offs must be carefully considered in overall conservation strategies. Second, historical and ongoing greenhouse gas emissions have already committed us to a certain degree of unavoidable climate change. If threatened bird populations are going to survive, they must do so under these new conditions of rapid global change. Efforts to create conditions in which birds can effectively adapt to ongoing and future climate change are referred to as **climate change adaptation**.

Which Species Are Most Vulnerable?

One key approach to the conservation of birds has been to focus on the needs of those particular species that are being most negatively affected by human activities, usually considered threatened and endangered species. In the context of climate change, the first step in this process is to identify the species most likely to be negatively affected by the kinds of climate change they will experience in coming decades (Foden et al. 2013, Pacifici et al. 2015). Gauging vulnerability to climate change involves estimating a species' **sensitivity**, **exposure**, and **adaptive capacity**. Sensitivity refers to how negatively a species may respond to changes in temperature and precipitation, such as unusual drought conditions or heat waves. Sensitivity is gauged through a careful examination of the ecology of a species in relation to climate and weather data. Exposure refers to the future climate changes that the species will actually experience and is typically gauged using climate models. Thus, some very sensitive species may not be greatly exposed within their limited range, and other species may be relatively insensitive to the kinds of climate variability to which they will likely be exposed. It is the combination of strong sensitivity and extensive exposure that poses the greatest risk. Adaptive capacity refers to the ability of species to overcome this risk through adaptive behaviors, such as dispersal to more favorable places, or through rapid evolutionary changes. Adaptive capacity can be strongly influenced by habitat conditions—for example, species that cannot disperse through highly fragmented habitat may have little capacity to colonize sites with more suitable climate conditions. A primary goal of

vulnerability assessment is to prioritize the most vulnerable species for conservation attention and identify specific conservation and management efforts that stand the best chance of maximizing the adaptive capacity of those species (Nicotra et al. 2015).

Bird Conservation Strategies in a Changing Climate

Most strategies for conserving species in the face of climate change rely on approaches that have already been developed to address other major threats to biodiversity, but with some important modifications. Continuing to manage protected areas such as national parks, reserves, and wildlife refuges for biodiversity conservation using an ecosystem-level approach ([chapters 27 and 28](#)) should help to ensure that vulnerable species have suitable habitat where chances for adaptation to climate change are best, because other threats are minimized. These areas may provide suitable areas for colonization by species of conservation concern, allowing the distributions of those species to shift in response to climate change. However, as land use has intensified in the broader landscape, protected areas have in effect become more isolated and island-like, making movement among them more difficult (DeFries et al. 2005, Radeloff et al. 2010). Thus, climate change adds emphasis to the need for creating greater **connectivity** among protected areas. Connectivity can be provided by maintaining and enhancing habitat suitability outside of existing protected areas, particularly in key locations that can act as **corridors** or stepping-stones for wildlife movement among protected areas. This can be achieved through a range of large-scale planning and management approaches that may include establishing new protected areas in key locations and working with landowners in places that are not exclusively managed for biodiversity protection, to encourage land uses that are nonetheless consistent with this goal (see the box on [page 770](#)). Most of the Earth's surface will not be included within designated protected areas, and will experience varying intensities of resource use, even as climate change adaptation requires that species have large areas for movement and colonization in order to persist. Thus, enhancing the conservation value of “working lands and seas” should be a high priority, even while more strictly protected areas remain a backbone of the conservation landscape.

In order to maximize the benefit of conservation activities in the limited areas where they can be undertaken, these areas should be carefully selected.

As climate changes, protecting threatened and vulnerable species requires that conservation actions take place not only where these species currently occur, but also where they are likely to have suitable climate conditions in the future. **Conservation planning**, which is concerned with prioritizing landscapes to efficiently achieve conservation goals, has only recently begun to address this complicating factor of potentially rapid change over time (Fuller et al. 2011). For example, expected geographic shifts in habitat suitability can be forecast with species distribution models (Franklin 2009). Combinations of such models for multiple species can be used to identify suites of locations that collectively can be expected to protect current and future habitat for the maximum number of species (Hannah et al. 2002).

Within areas that have been identified for some kind of conservation activity, a variety of ecosystem management and restoration activities may be undertaken, depending on the condition of existing habitat and the needs of particular species. Creating optimal habitat conditions for bird species of concern is likely to maximize their resilience and adaptive capacity to climate change in those landscapes. However, because multiple bird species with different specific habitat affinities may be of concern, an ecosystem approach to management is often called for (Christensen et al. 1996, West et al. 2009). Management activities to achieve this typically include establishing and maintaining diverse plant communities, controlling invasive predators, competitors, or nest parasites, and establishing ecological disturbance regimes (e.g., prescribed fire) within historical ranges of variability. However, climate change is also likely to push many ecosystems into new states, and maintaining formerly “normal” conditions may become untenable. Under these circumstances, effective bird species conservation will entail recognizing these inevitable changes and working with them. This means continuing to implement active management techniques that can provide suitable habitat for a wide range of species, even if the collection of species found in a given conservation landscape bears little resemblance to the bird communities of the past (West et al. 2009, Fuller et al. 2011).

LANDSCAPE CONSERVATION COOPERATIVES

The Landscape Conservation Cooperative (LCC) Network is an applied science partnership with the shared goal of conserving landscapes to

sustain natural and cultural resources for current and future generations. The LCCs represent an effort to address large-scale conservation challenges, climate change being the premier example, by developing science-based conservation strategies that are coordinated across large landscapes and across administrative boundaries. Housed within the US Department of the Interior, the network's 22 self-directed cooperatives are associated with multistate regions that collectively include most of North America, and partners within each cooperative include federal, state, and tribal natural resource agencies and nongovernmental conservation organizations. At the time of this writing, the LCC network is a young institution that promises to become a significant platform for researchers and conservation practitioners to bring science addressing the consequences of climate change together with applied ecosystem management, helping to meet the challenges of biodiversity conservation in a rapidly changing world (LCC Network, 2014).

It is possible that climate change will be too rapid, and habitat too fragmented, for some species to colonize newly suitable areas quickly enough to avoid extinction. This has not yet been observed, but species at risk of this eventuality are likely to be habitat specialists already reduced in numbers by other human-caused threats, with strong climate change vulnerability and poor dispersal ability. **Assisted colonization**, or assisted migration, is a proposed approach that entails introducing such species to new areas, possibly outside their existing range, as climate change makes those areas suitable (Hoegh-Guldberg et al. 2008). While a promising idea, this method should be considered a last resort after other ecosystem management efforts have failed. The risk that species introduced to new environments may become invasive, and have negative impacts on other species, is well documented, though the likelihood of this happening will depend on the ecology of the species and environments in question. Carefully measuring extinction risk against possible negative effects to other at-risk species and broader ecosystem functions will be crucial in the ongoing consideration of this approach.

Effects of Climate Change Mitigation on Birds

Efforts to reduce greenhouse gas emissions and their atmospheric concentrations are a first priority in combating climate change. The net effect of these mitigation efforts will be beneficial for birds if they are successful in reducing underlying causes of climate change and rendering more extreme adaptation efforts unnecessary. Nonetheless, existing approaches to achieving this, particularly renewable energy production methods, can be detrimental to bird populations in other ways.

Carbon sequestration refers to the storage of carbon to prevent it from contributing to atmospheric greenhouse gas concentrations. The standing biomass of terrestrial and ocean ecosystems, such as that in forest trees and soils, is a primary form of carbon storage. The need for carbon sequestration can therefore help to create and maintain habitat for birds, particularly in forest habitats. Incentives for carbon sequestration efforts, however, do not necessarily result in land use decisions that improve conservation outcomes (Nelson et al. 2008). For example, some vegetation types, such as single-species tree plantations, can provide carbon storage but have little bird conservation value. Delivering on the potential for win-win solutions for both carbon sequestration and biodiversity protection depends on ensuring that adequate attention is given to the biodiversity impacts of particular sequestration approaches.

Wind power, hydroelectricity, solar power, and agricultural bioenergy production all promise to reduce carbon emissions by reducing reliance on fossil fuels, but they also involve land use changes and infrastructure development that can have negative effects on bird populations. These effects accrue through habitat loss, disruption of ecosystem processes, or direct effects of infrastructure such as bird collisions with wind turbines. Collisions with turbines may be the most apparent negative effect of large wind energy farms, particularly because raptors and other large birds such as geese and seabirds tend to be the most at risk, but some species can also suffer a less visible form of habitat loss when they naturally avoid areas with large towering structures, even if otherwise suitable habitat is present (Drewitt and Langston 2006, Pearce-Higgins and Green 2014). Solar energy production may pose the lowest risks among renewable energy options, whereas some of the most negative impacts on wildlife to date have resulted from the large-scale conversion of tropical forests for agricultural biofuel production. In addition to direct biodiversity losses associated with forest loss, the conversion of forests for biofuel production also releases sequestered carbon,

negating the climate benefits of biofuel production under such circumstances (Fargione et al. 2008).

Minimizing the negative effects of renewable energy projects will involve careful siting of infrastructure away from areas of heavy wildlife use such as important migration corridors and large wetlands, as well as adopting improved technologies and methods. Bioenergy production may be made more benign, for example, by siting on existing agricultural lands and utilizing diverse mixes of native plant species that supply usable habitat for grassland and open-country birds. Even efforts to minimize negative impacts can be complicated by unexpected trade-offs—for example, newer wind turbines that are larger in size and therefore can replace the energy production capacity of several smaller turbines appear to result in a reduction of overall bird collision rates, but they may actually increase bat collision rates (Barclay et al. 2007). Ultimately, all methods of energy production have some effect on wildlife populations, and probably the best hope for minimizing these negative effects is to minimize energy consumption. While beyond the scope of this book, reducing per capita energy consumption particularly in wealthy nations is both a great societal challenge and a necessary centerpiece of efforts to address the hazards of climate change.

KEY POINTS

- In recent decades, timing of seasonal events (spring arrival and egg-laying dates) has advanced consistent with earlier spring phenology.
- There is evidence that a phenological mismatch between birds and their food resources has important implications for population dynamics (although some species and guilds are likely more vulnerable than others).
- Species are shifting their distributions (primarily poleward and upslope) over recent decades, leading to unanticipated species interactions.
- Extreme events (flooding, heat waves, ice storms) have been cautiously attributed to modern climate change and can have wide-ranging impact on avian demographics in tropical, temperate, and polar environments.
- Range shifts can lead to novel bird communities, and increases in species richness have been observed in northerly latitudes experiencing strong warming.
- Certain species or groups (seabirds, upland birds, woodland birds) are

likely to be more sensitive to climate change because of their particular life history characteristics (although this could result from a sampling bias).

KEY MANAGEMENT AND CONSERVATION IMPLICATIONS

- Human-caused climate change is already affecting bird populations, and these effects will only strengthen over time; climate change adaptation efforts are needed to help ensure the survival of species vulnerable to the negative effects of climate change to which the world is already committed.
- Climate change vulnerability assessments can help to focus conservation attention on the most at-risk species and populations.
- Negative effects of climate change will compound the effects of other stressors such as habitat loss and fragmentation.
- Climate change places greater importance than ever on an all-lands, ecosystem management approach to bird conservation, with protected areas as well as working lands playing crucial roles.
- Climate change mitigation efforts such as the shift to low-carbon energy sources (wind, solar) are essential, but these efforts may themselves have negative impacts on bird populations (and other taxa), which should be addressed.

DISCUSSION QUESTIONS

1. When studying poleward shifts in bird distributions, researchers often focus on quantifying the range boundaries. Why might range boundaries be sensitive to climate change? What specific aspects of population dynamics would be responsible for expanding or retracting range boundaries?
2. In studies of phenological mismatch, researchers have found differential rates of advancement for trees, caterpillars, resident birds, migrant birds, and predators on birds. If all these groups are experiencing the same shifting climate conditions, what is the possible cause of these different rates of advancement?
3. How might behavioral plasticity be important for mitigating the population-level consequences of extreme weather (e.g., drought, storms, and heat waves)?
4. Why might birds in tropical montane ecosystems be more affected by rising temperatures than birds occupying temperate montane systems?
5. How might habitat fragmentation and climate change interact to cause more stress on bird populations than either of these two factors would cause in isolation from each other?

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