CHAPTER 18

Climate change in other taxa and links to bird studies

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18.1 Introduction—Links between birds and other organisms

Birds occupy a variety of positions in food webs, serving as herbivores, predators, omnivores, pollinators, hosts, and prey. Given this variety of ecological roles it's not surprising that climate change can affect their interactions with other taxa in myriad ways. The direct effects of climate that can influence birds' interactions with other species include the phenology of migration (Kullberg et al. 2015; Cadahia et al. 2017; Courter 2017; Kolarova et al. 2017; Probst et al. 2017), and changes in distribution (Thomas and Lennon 1999; Hitch and Leberg 2007; Doswald et al. 2009; Zuckerberg et al. 2009; Freeman and Class Freeman 2014; Bateman et al. 2015), including elevational range changes (Tingley et al. 2012). Birds' attempts to remain within their historic climate zones (Tingley et al. 2009), can generate changes in local abundance (Huang et al. 2017) and potentially new kinds of interactions as they interact in reassorted communities.

18.2 What can we learn from studies of other taxa?

Birds are embedded in communities and ecosystems, and depend on other taxa for resources such as food and nest sites. They interact with other species in sometimes extensive networks that include predators, prey, competitors, and parasites, and can serve as mutualists in dispersal or pollination. These networks change over time and space, as birds may rely on different resources at different ages, or different times of the year, and will encounter different ecological communities as they migrate or change latitudinal or altitudinal distributions in response to the changing climate. Thus, a complete understanding of the ecological or conservation status of a bird species will require data on a host of other taxa, all of which are likely to be responding to the changing climate. An understanding of these responses will help set the context for understanding how and why avian species are in turn responding to the changing climate.

18.3 Overview of effects across trophic levels (i.e., what happens when ecological linkages are stretched or broken?)

Whether the bird species are herbivores or carnivores, resident or migratory, their interactions with the species they depend on for nutrition are likely being affected by the ongoing changes in phenology, distribution, and abundance of both plants and animals. The Green Wave Hypothesis is that migrating animals should track or 'surf' high-quality forage at the leading edge of spring green-up (Merkle et al. 2016), and evidence for large mammalian herbivores

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provides some support for it (Bischof et al. 2012). It also has some support from the avian literature. For example, herbivorous waterfowl such as geese that reproduce in the Arctic are faced with different responses by plants along their migratory route that may disrupt the historical pattern of the 'green wave' of spring along the latitudinal gradient. Lameris et al. (2017) used warming experiments to study the effects of warming on plant biomass and nitrogen concentration at three sites along the migration route of barnacle geese (*Branta leucopsis*), and found that the experimental warming increased biomass accumulation but sped up the decline in nitrogen content at the Arctic breeding site but not at the lower-latitude wintering site or stop-over sites. They concluded that warming will likely change the arrival dates in the Arctic and result in a phenological mismatch, and negatively affect reproduction.

Climate change effects on small mammal populations in the Arctic (e.g., lemmings) can cascade into effects on their avian predators (snowy owls, *Bubo scandiacus*; long-tailed skuas, *Stercorarius longicaudus*) (Schmidt et al. 2012). For example, arctic ground squirrels have lower survival in areas where shrubs are encroaching, making them more susceptible to predators (Wheeler et al. 2018). A lack of snow cover for insulating the ground can also influence small mammal populations; in the winter of 2017–18 in Colorado, with near-record low snowfall, the ground froze and appeared to cause the local extinction of pocket gophers, which have to be able to access the ground surface during the winter to deposit dirt from their tunnels as they excavate roots for food (Inouye, pers. obs.).

Temperature can affect the abundance and the timing of migrations of fish (Taylor 2008; Kuczynski et al. 2017), which can have consequences for avian predators. Insect migrations are also changing, with potential consequences for insectivorous birds (Bell et al. 2015). The phenology of emergence from hibernation by mammals (Inouye et al. 2000; Lane et al. 2012; Sheriff et al. 2013), and of abundance of insect species (Ellwood et al. 2012; Boggs 2016; Forrest 2016; Scranton and Amarasekare 2017) are changing in response to climate change, and because these species can be important food resources for birds, there are potential impacts on these predator–prey interactions.

Given the large number of interacting species in ecological communities it's not surprising that they would exhibit disparate responses to climate change, resulting in unequal rates of change in phenology over time, and hence the potential for phenological mismatch as warming progresses (Ovaskainen et al. 2013). There are a few instances where we have information on how prey species are changing their phenology, and how bird species are responding. For example, the onset of breeding by pied flycatchers (*Ficedula hypoleuca*) and great tits (*Parus major*) in Scandinavia is tracking closely the spring phenology of local insects (Valtonen et al. 2017). In another study, however, caterpillar prey phenology was changing more rapidly than that of predatory birds (Visser et al. 2006; Burger et al. 2012), Similarly, hummingbird arrival dates at the end of migration to the breeding ground are changing, although not as quickly as the flowering dates of their floral resources (McKinney et al. 2012). Thus, historical patterns in phenology can change at different rates in different species, creating new patterns of phenological mismatch that can break food web links due to temporal or spatial changes in distribution. These mismatches can have significant consequences for fitness of bird populations (Senner et al. 2017), although if the birds have sufficient flexibility in their foraging behaviour they may be able to compensate (Mallord et al. 2017).

Not all impacts of climate change cascade into negative effects on birds, however. For example, the rapid melting of Arctic glaciers can affect phytoplankton and raise them closer to the surface, making them more accessible to seabirds, facilitating their foraging and reproduction (Stempniewicz et al. 2017).

18.3.1 Birds as hosts (disease, parasites)

Parasites and their vectors are also subject to changes in their distribution and abundance as a consequence of the changing climate. For example, the altitudinal distribution of malaria-bearing mosquitoes has increased in Hawaii, which has had an impact on native Hawaiian birds (Atkinson et al. 2014; Glad and Crampton 2015; Liao et al. 2017). A similar pattern has been observed in the Colorado Rocky Mountains, with disease-transmitting mosquito

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species moving up in altitude and affecting hosts that previously reproduced at altitudes high enough to avoid them (R. Conover, pers. comm.). Increasing latitudinal distribution of avian malaria is also a concern, as shown by recent studies in Alaska (Loiseau et al. 2012) and France (Loiseau et al. 2013). West Nile virus is another disease that can affect birds, and its distribution is also being affected by climate change (Harrigan et al. 2014). The diverse parasitic taxa that can affect birds, including protozoa, feather parasites, diptera, ticks, mites, and fleas, may in part be buffered from climate change by virtue of living on their avian hosts, but parasite abundance is increasing over time, with consequences for clutch size, brood size, and body condition (Møller et al. 2014). Warming in the Arctic may facilitate trematode life cycles, making it more likely they will parasitize avian hosts (Galaktionov 2016).

18.3.2 Birds as prey

Polar bears have been strongly affected by the warming climate and subsequent loss in the distribution of sea ice, as this affects their ability to harvest seals as prey (Hamilton et al. 2017). An unforeseen consequence has been increasing predation on bird eggs, nestlings, and even adults (Dey et al. 2017; Waters 2017). Some bird species depend on camouflage for protection against predators. Ptarmigan (*Lagopus* spp.) are an example, and they change their plumage colour to white during the winter to provide a match with the snow. But as the temporal pattern of snow cover diminishes, there is the potential for them to turn white before the ground is white, and to remain white after the snow melts, which would greatly increase the ability of predators to spot them. A similar problem faces snowshoe hares (*Lepus americanus*) (Zimova et al. 2014), which can experience strong selection on coat colour phenology; animals mismatched with the background experienced weekly survival decreases up to 7 per cent (Zimova et al. 2016).

18.3.3 Habitat

Most bird species have relatively specific habitat requirements, often determined by the type of vegetation present. For example, woodpeckers need trees, and some birds require alpine tundra. Tree distributions in turn determine woodpecker distributions; a recent survey of Picid distributions found that there was a strong positive relationship between woodpecker species richness and current tree cover and annual precipitation, respectively (Ilsoe et al. 2017). Because we know from climate models and recent empirical evidence that precipitation patterns are changing, and that tree distributions will too, we can infer that woodpecker distributions will have to change too. Modelling studies suggest that many plant species will respond to climate change with altered distributions and abundances. For example, the alpine area in the Italian alps, the suitable habitat for rock ptarmigan (*Lagopus muta*), is projected to decrease by up to 49 per cent, largely because there is insufficient area for that habitat to expand above its current altitudinal distribution (Ferrarini et al. 2017). Piñon-juniper woodlands in the western USA have experienced large-scale mortality in the past few decades, with reduced canopy cover and decreased cone production, and climate models predict these trends will continue (Johnson et al. 2017). This will have a large impact on distribution and abundance of the several bird species, such as pinyon jays (*Gymnorhinus cyanocephalus*), that rely on pine nuts from those trees.

We know that birds can respond to changes in habitat and temperatures by changing their distribution. A study of European species found that their ranges expanded north by 37 km between 1990 and 2008, but the climate envelope shifted much more rapidly, creating a 212 km 'climate gap' (Devictor et al. 2012). By comparison, the gap for butterfly species was only 135 km behind the climate. This is further evidence that ecological communities including birds are in the process of reassorting, and that these changes will continue for a while even if humans are able to slow or halt the ongoing climate change.

18.4 Case studies

18.4.1 *Delphinium* species and climate change effects on hummingbird resources

Broad-tailed hummingbirds (*Selasphorus platycercus*) are a resident breeding species at the Rocky Mountain

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Biological Laboratory (RMBL), in Colorado, USA. They depend on a variety of wildflowers for nectar in this montane environment, some of which are specialized for pollination by hummingbirds, and others of which are shared with other pollinators like bumble bees. At this study site, we have long-term records of the weather, snowfall and snowpack, and phenology and abundance of wildflowers. We also have data on arrival dates of males in the spring (McKinney et al. 2012), These data have shown us that the growing season is typically starting earlier now than it used to, reflecting warmer spring temperatures and earlier snowmelt, and hence flowering is trending earlier. The migratory hummingbirds are arriving earlier than they used to, but their phenological advance is not matching that of some of the wildflowers that they rely on, suggesting that if these trends continue the earliest-flowering species visited by hummingbirds may eventually finish flowering before the birds arrive (McKinney et al. 2012).

The changing climate is also having effects on floral abundance, as the frequency of frost damage to flowers has increased (Inouye 2008), and because lower snowpack is correlated with lower flower production of some of the flowers that hummingbirds visit (Inouye and McGuire 1991; Inouye et al. 2002; Saavedra et al. 2003; Miller-Rushing and Inouye 2009). At least at one level, we know that hummingbirds respond to variation in flower abundance; in years with high abundance we caught fewer hummingbirds at feeders (Inouye et al. 1991). We interpret this as showing that birds may travel greater distances to feeders in years with lower flower abundance, when they may not find enough nectar in wildflowers close to nest sites. In addition to the changes in abundance, we also know that there is a community-level reassortment of phenology taking place at RMBL. Some species are advancing significantly while others are not changing, and many are also changing the shape of their flowering curves in ways that alter patterns of co-flowering (CaraDonna et al. 2014).

We also know that variation in floral resources is affecting another important group of pollinators in the montane meadows, bumblebees (Ogilvie et al. 2017). These bees are also moving up in altitude, presumably in response to the changing climate (Pyke et al. 2016). Bumblebees share some floral resources with hummingbirds, so changes in their distributions have the potential to impact the birds. Probably not in response to changing resources, but more likely in response to the warming temperatures, it seems that black-chinned hummingbirds (*Archilochus alexandri*) are moving up in altitude; we observed a male at 9500 feet for the first time in 2017.

In the same habitat other species are also responding to the changing climate. Foxes have increased their altitudinal range, as have moose, mosquitoes, fish, and a ground squirrel species. Yellow-bellied marmots (*Marmota flaviventris*) now emerge from hibernation about three weeks earlier than they did in the 1970s (Inouye et al. 2000), and put on significantly more fat than before, which has resulted in decreased winter mortality (Ozgul et al. 2010). Ground squirrels and chipmunks in the same habitats are also changing their hibernation behaviours, although not in the same way as marmots (B. Barr, pers. comm.). These results are similar to those reported for a red squirrel population in the southwest Yukon, Canada, for which timing of breeding has advanced by 18 days in a 10-year period, prompted by increasing spring temperatures and food supply. The researchers attributed the change to a combination of phenotypic changes within generations and genetic changes among generations, in response to the rapidly changing environment (Réale et al. 2003).

18.4.2 Caterpillars, birds, and trees

Birds that rely on caterpillars to feed nestlings in the spring are at the mercy of two trophic levels, the trees that produce leaves and the Lepidoptera whose caterpillars eat those leaves. Both the plant and herbivore species respond to changes in their phenology as the temperature warms, with earlier leaf-out dates and earlier hatch dates for caterpillars, but their responses are not synchronized. Thus the warming climate is disrupting the historical synchrony, for example of oak trees and winter moths in the UK (Visser and Holleman 2001). In turn, the changing but disparate responses of caterpillars and birds have affected great tit reproduction (Visser et al. 2006). Similar patterns of phenological change have also been implicated in population declines of the trans-Saharan migratory wood warbler *Phylloscopus sibilatrix* (Mallord et al. 2017).

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18.4.3 Frost effects in a warming world

A paradoxical consequence of climate warming has been an increase in the incidence of late-spring frost events, which can have ecosystem-wide effects (Gu et al. 2008). This is an outcome when the advance in green-up timing outpaces that of the last spring freeze. For example, at 9500 feet in the Colorado Rocky Mountains the date of the last spring frost was historically about 10 June, and although the date of snowmelt has advanced, sometimes occurring in mid-April on south-facing slopes, the last frost date has not advanced significantly (Inouye 2008). A consequence is that the growing season starts earlier, so that frost-sensitive plant species may have developed buds by the time the frost arrives, sometimes causing close to 100 per cent mortality. If the buds are killed, there are then no floral resources for pollinators, or seeds for the variety of animals that rely on them, and there will be no seedlings the following spring. This phenomenon of 'false spring' warming events that trigger flowering is also having severe consequences for agriculture, such as the loss of fruit following frost events in 2007 and 2012 that caused billions of dollars of losses to mid-west and eastern US agriculture (Peterson and Abatzoglou 2014), and it can have consequences for both insects and small mammals (Inouye 2000).

18.5 Critical needs and future directions

Studies of the ecological effects of climate change are somewhat challenging if you rely on observational data, as those data are only accumulated at the rate of one datum per year, and there can be substantial inter-annual variation that may require decades of observations before clear trends are evident. What was the arrival date of the migratory species on its breeding ground? What is the first date of flowering? Or what is the peak abundance of the resource of interest? Thus, access to long-term historical datasets is valuable because they can document the relationship between the ecological variable of interest and an appropriate climatic variable. Climate projections can then be combined with the historical data to permit forecasting of the effects of future climates on the ecological variables or interactions of interest. In this context, the citizen science efforts of programmes such as the USA National Phenology Network, Bumble Bee Watch, or the variety of programmes supervised by the Cornell Lab of Ornithology, are tremendous opportunities both for interested participants and for the scientists who can benefit from those datasets about birds, their food sources, and other species with which they interact. The data on spatial distributions, and how they are changing (both latitude and altitude), and data on abundances are all opportunities for non-scientists to contribute to our understanding of the ecological effects of climate change.

Another opportunity for data collection is the increasing frequency of extreme weather events, which in turn generate consequences such as heat waves, wildfires, and floods, which can have dramatic consequences for plant and animal species. Responses can be rapid, such as the recent mass mortality of flying foxes in response to record high temperatures in Australia (https://news.nationalgeographic.com/2018/01/australian-heat-wave-flying-fox-deaths-koala-spd/), or slower, such as the bleaching of coral reefs in response to warming ocean temperatures. Climate change vulnerability assessments (Wheatley et al. 2017) are one way to gain insights into how these events may influence distribution and abundance of flora and fauna in the future.

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